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SIMULATION MODELING AND ANALYSIS OF BORDER SECURITY SYSTEM

A THESIS
SUBMITTED TO THE DEPARTMENT OF
INDUSTRIAL ENGINEERING
AND THE INSTITUTE OF ENGINEERING AND SCIENCE
OF BILKENT UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

By
Gökhan ÇELİK
July, 2002

I certify that I have read this thesis and in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

SIMULATION MODELING AND ANALYSIS OF BORDER SECURITY SYSTEM

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M.S. in Industrial Engineering
Supervisor: Assoc. Prof. İhsan Sabuncuoğlu
July, 2002

Border control is vital to the security of the nation and its citizens. Hence, states all around the world look at measures to increase the security of their borders. On the other hand, increasing border security also brings significant financial costs.

In this study, the performance of a Border Company is analyzed by simulation modeling of the operational activities of a Border Company supported by Border Battalion. Our main objective is to find out more efficient ways of increasing border control and security along the land borders of Turkey. To achieve this objective, we examine the border security system structure and its components, observe the relationships between performance measures, and find out effects of security elements on the system performance measures. We also investigate system responses when changes implemented in the system or new resources added, evaluate different alternatives that improve the performance measures by using ranking/selection and multi-criteria decision-making procedures. The model is developed by using ARENA simulation system and the results are analyzed by using SPSS statistical package program. A comprehensive bibliography is also provided in the thesis.

Key Words: Military Simulation, Border Security

ÖZET

HUDUT GÜVENLİK SİSTEMİNİN SİMÜLASYONLA MODELLENMESİ VE ANALİZİ

Gökhan Çelik
Endüstri Mühendisliği Bölümü Yüksek Lisans
Danışman: Doç. Dr. İhsan Sabuncuoğlu
Temmuz 2002

Sınır kontrolu bir millet ve vatandaşlarının güvenliği için hayati öneme sahiptir. Bu sebeple, dünyadaki tüm devletler sınırlarının güvenliğini artırmak için önlemler aramaktadırlar. Diğer taraftan, sınır güvenliğini artırmak önemli maliyetler getirmektedir.

Bu çalışmada, Hudut Taburu tarafından desteklenen bir Hudut Bölüğü'nün harekata yönelik faaliyetleri modellenerek, Hudut Bölüğü'nün performansı analiz edilmektedir. Ana hedefimiz, Türkiye'nin kara sınırları boyunca sınır güvenliğini ve kontrolunu artırmak için daha etkin yöntemler ortaya çıkarmaktır. Bu amacımıza ulaşmak için, hudut güvenlik sisteminin yapısı ve bu sistemin bileşenleri incelenmekte, performans ölçütleri arasındaki ilişkiler gözlemlenmekte ve güvenlik elemanlarının sistem performans ölçütleri üzerindeki etkisi tespit edilmektedir. Ayrıca, sistemde değişiklikler yapıldığında veya yeni kaynaklar ilave edildiğinde sistemdeki etkileri incelenmekte, performans ölçütlerini geliştiren değişik alternatifler sıralama/seçme ve çok amaçlı karar verme yöntemleriyle değerlendirilmektedir. Model ARENA simülasyon programı kullanılarak hazırlanmıştır. İlgili referanslar tezde verilmiş bulunmaktadır.

Anahtar Sözcükler: Askeri Simülasyon, Hudut Güvenliği

To my wife Sena

ACKNOWLEDGEMENT

I would like to express my deep gratitude to Dr. İhsan Sabuncuoğlu for his guidance, attention, understanding, motivating suggestions and patience throughout all this work.

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Gökhan ÇELİK

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CHAPTER 1

Introduction

It is a well-known fact that the border control is vital to the security of the nation and its citizens. The threat of international terrorism, worldwide illegal immigration and refugee problems, drug and arms smuggling are issues of that concerns states. Therefore, all states in the world look at measures to increase security at their borders. They apply different organizations and methods to protect their borders. But the main resources are technology and personnel. Therefore, increasing border security is only possible by increasing resources or improving methods. On the other hand, increasing resources causes significant financial costs.

In our thesis, we investigate the possible ways of increasing border control and security along the land borders of Turkey. First, we present brief information about how Turkey protects her land borders.

1.1. Protection and Security of Land Borders in Turkey

Turkey has land borders of 2852 kilometers long with neighbor countries (202 km with Greece, 268 km with Bulgaria, 877 km with Syria, 378 km with Iraq, 528 km with Iran, 17 km with Nahcıvan, 325 km with Armenia and 257 km with Georgia). In Turkey, the task of protection of land borders and providing security along the borders was given to the Land Forces by law at 10.11.1988. This task is executed by Border Troops.

1.1.1. Tasks of Border Troops

The tasks of border troops are as follows:

Peace Time

- To protect the land borders and to provide security along the borders in its responsibility terrain.
- To prevent smuggling and related illegal activities.
- To prevent trans-borders crimes unauthorized entry into or exit from the territory of Turkey (such as illegal infiltrations of refugees, terrorists, smugglers, enemy special forces).
- To coordinate with civil administration.
- To get prepared for war according to general defense plans.
- Collection of intelligence.

War Time

- To execute tasks according to general defense plans.
    - To hold ground in less threatened sectors so long as the main attack does not develop in a particular sector.
    - Protection of vital installations against enemy commandos and paratroop raids.

Border troops execute their tasks under the light of laws, regulations, and rules of our country, and treaties or protocols with the neighbor nations' administrations.

1.1.2. Organization and Deployment of Border Troops

Border troops are organized by the proposals of Land Forces and approval of the General Staff. Each border troop may have different organizations, which are determined by order. Main organization scheme is shown in Figure 1.1. Border battalions consist of three border companies and one headquarters company. Headquarters company supports the activities of border battalion commander and his headquarters. It also provides logistic support for border companies. Border companies are operational troops of border battalion. It can be said that the main force that protects the land borders of Turkey are border companies. Border companies consist of three border platoons and one center platoon. Center platoon supports border company headquarters. Operational tasks such as patrol and ambush are executed by border platoons. Sometimes center platoon supports border platoons. Border troops are equipped with new technology and supported by personnel to execute their tasks best.

Border troops are located in such a way that they execute their tasks best under peace and war conditions. Any change of locations is under the authority of General Staff. Unless permission is given, no change can be done in the location of border posts.

Brigade commanders determine the responsibility terrains of border troops. Basically, border platoons (border posts) are located along the borders and border companies that direct and manage the border platoons are located behind the platoons, lastly border battalions are located behind the border companies. The scheme of deployment is shown in Figure 1.2.

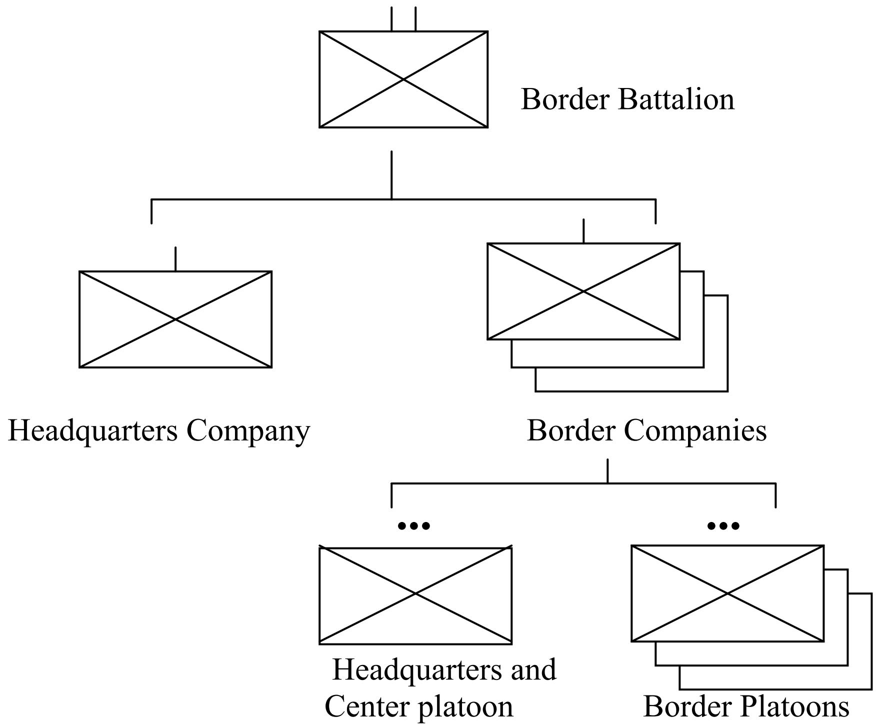


Figure 1.1. Main organization scheme of Border Troops

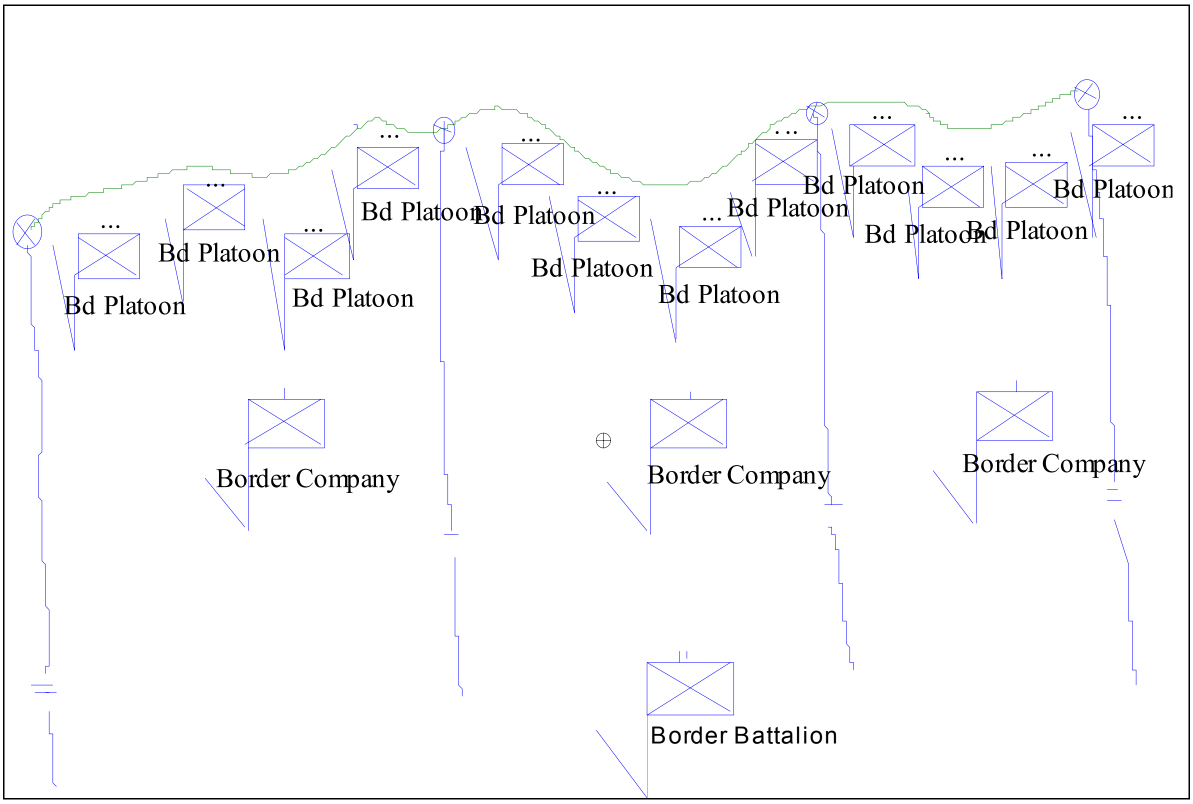


Figure 1.2. The scheme of deployment

1.2. Border Security System

Border Security System consists of physical obstacles system and border surveillance and controlling system. These complementary systems can be used as a whole or they can be used partially depending on needs and possibilities. At this point, the importance of the region, threat and structure of the terrain are considered.

The Ministries of Defense and Home Affairs are also responsible for installing and maintenance of the physical obstacles system. These obstacles are:

- Fences along the borders, barbed wires (8 meters width along the borders).
- Track fields (7 meters width along the borders).
- Ways for patrols and illumination area (7 meters width along the borders).

Border surveillance and controlling system is the main part of the border security system. Because it contains all active precautions against unauthorized entry into or exit from the territory of Turkey. It is the basic means of providing security along the borders. Border Patrols, ambushes, sentries, thermal cameras and askarad are the main elements of this system.

Border Patrols: A patrol consists of three soldiers (one of them is the commander of the patrol) and they execute their tasks by watching and controlling the areas on their route along the borders. These soldiers belong to border platoons and they leave for task from border posts in some time intervals, execute their tasks and return border posts. They control the borders under day and night conditions.

Ambushes: An ambush consists of five-six soldiers under the command of commissioned or non-commissioned officer. Ambushes may be stationary or mobile. If they are stationary, they go to the place where they control the area through the night. If they are mobile they change their places after execution of their task at one place. They change their places 3 or 4 times and they stay at one place no more than 2-3 hours. Ambushes may be equipped with night-vision devices. If they have night-vision devices, the area that they control gets wider. Ambushes execute their tasks under night conditions.

Sentries: Their main task is to watch the borderlines and enemy terrain. They execute their tasks at watchtowers, which are constructed at some specific places along the borders. Sentries are on duty under day conditions. Watching duty is executed by using electronic systems such as askarad and thermal cameras under night conditions.

Thermal Cameras: Thermal Camera System is an infrared imaging system, which enables the user target detection, recognition and observation capabilities in all weather conditions. The passive nature of imaging provides fully covert surveillance. Light-weight and portable structure, operability by one man, operability with 12-24 VDC sealed lead acid battery or 220 VAC at stationary applications, minimum focusing range, uninterrupted operation capability without being affected from poor field and weather conditions, low noise level and perfect imaging make thermal camera an ideal system for military purposes. Thermal cameras are used for; border surveillance, protection of headquarters, military zones and port/harbor surveillance. Thermal Cameras are under the control of Border Company. They can be used only under night conditions, stationary or mobile.

Askarad: Askarad, ground surveillance radar, is a new generation radar system used for surveillance of moving targets and for artillery fire adjustment in the battlefield. Askarad combines surveillance, target acquisition and classification, target tracking and artillery fire adjustment functions within one unit. Askarad is used for; surveillance, target acquisition and moving target classification, precision location of targets, plotting of targets on the display, adjustment of artillery fire, guidance of small ground or airborne attack units, helicopter navigational aid especially for homing. Askarads are under the control of Border Battalion. They can be used under day and night conditions, as stationary or mobile.

Both thermal camera and askarad are electronic surveillance systems. Main difference between them is the range that they are capable of control. Askarad is capable of detecting targets from 4-5 times farther than that of thermal camera.

1.3. Objectives and Scope of the Thesis

In this thesis, our main aim is to investigate how to increase border control and efficiency of border security along the borders of Turkey. To achieve our purpose, we model the operational activities of border company supported by border battalion via simulation. We first study border security system structure and its components. At this stage, our aim is to assess the effectiveness of the system in terms of performance measures such as the ratio of illegal infiltrations caught, degree of controllability and frequency of controlling. Secondly, we attempt to understand the relationship between security elements and performance measures. In other words, we observe the behavior of the system and interactions of security elements and performance measures closer. Thirdly, we investigate effect of each security element on the performance measures and find out the degree of importance of each security element. Fourthly, we analyze the significant factors that affect the performance measures. Fifthly, we investigate system responses, when changes made in the system or new resources added to the system. Lastly, we evaluate different alternatives that increase the performance measures, by using ranking, selection and multi-criteria decision-making procedures. At the end, we hope to find possible ways of increasing border security by a simulation model of the system that can be used before implementing real investments in the system or real decisions about the system.

The outline of the thesis is as follows. Chapter 2 presents the literature review about border security systems in the world, simulation methodologies and military simulations. In Chapter 3, we give the simulation model of border security system. Verification and validation issues are also discussed in this section. In Chapter 4, the system behavior is examined, the interactions of system components and performance measures are found out and effects of each security element on the performance measures are investigated. Chapter 5 presents experimental design and implementation of analysis of variance procedure to find out the significant factors that affect the performance measures. In Chapter 6, alternatives are examined, compared and they are ranked and selected by using ranking and selection procedures and multi-objective decision-making procedures. Chapter 7 gives conclusion of the study and future research directions.

CHAPTER 2

Literature Review

During our literature review, we search for the studies or researches that are related with analysis of border security systems via simulation. We also search for how to increase border security. Although there are some official studies those are about precautions taken for more secure borders, we couldn't meet any study that simulation tool is used in the analysis of border security systems in the literature. Furthermore, we observe that the border security systems vary from country to country, but the basic components and operational activities of the systems are similar. Thus, we first give information about border security systems from other countries and precautions taken for more secure borders. Then, since we use simulation tool to analyze our border security system, we search for simulation methodology and software. We also review the military simulation studies to learn how to deal with the subject and to overcome the problems.

2.1. Border Security in the World

During our survey, we examine how the other countries protect their land borders. There are mainly three kinds of organization that countries apply to protect their land borders. One of them is giving this task to the Army. This method is used in our country and in our neighbor countries. The second method is performing this task by state organizations rather than Army. These organizations are under the control of civil administration. An example of this method is U.S. Border Patrol organization that is under the control of Immigration and Naturalization Service of Department of Justice. Sometimes these organizations are supported by Army. The third method is execution of this task by Police Forces. At wartime, these forces are under the operational control of the Army. But at the peacetime, they are under the control of the Ministry of Home Affairs. This method is applied in India and this organization is called as Border Security Force.

As seen, when the border security is the subject under concern, the main ministries, departments and armed forces of the states have responsibilities for security of country borders. Therefore, besides many news those are related with border security of countries from all around the world such as declarations of researches for more secure borders or precautions and results of precautions in both technological and organizational issues, we meet some official reports related with border security.

There are several reports of GAO (General Accounting Office is the investigative arm of Congress in U.S.) and CRS (Congressional Research Service) related with border control and security.

In their CRS report (June 18, 2001), William J. Krouse (Analyst in Social Legislation; Domestic Social Policy Division) and Raphael F. Perl (Specialist in International Affairs; Foreign Affairs, Defense, and Trade Division) explain the importance of border security and propose some options to prevent illegal entry into the United States.

In GAO reports, after making studies about border security, precautions are proposed and results of precautions are evaluated. As precautions for strengthening the border, (1) concentrating personnel and technology resources, starting first with the sectors with the highest level of illegal infiltration activity and moving to the areas with the least activity, (2) making maximum use of physical barriers to deter entry along the border, (3) increasing the proportion of time Border Patrol agents spent on border control activities and (4) identifying the appropriate quantity and mix of technology and personnel needed to control the border, are proposed in some parts of GAO reports.

2.2. Simulation Methodology and Software

We use simulation tool to analyze border security system. Throughout our study, we use the basic principles, which are stated in Shannon (1998), Banks (1998) and Mehta (2000). In these studies, they explain how a complex simulation study of any discrete system be executed efficiently and effectively following simple basic methodology.

Sargent (1999) discusses validation and verification of simulation models and different approaches are presented to decide model validity. Robinson (1997) sets simulation model verification and validation in the context of the process of performing a simulation study. Balcı (1998) presents guidelines for conducting verification, validation and accreditation of simulation models. Fifteen guiding principles are introduced and many verification and validation techniques are presented. We verify and validate our model by using techniques and considering the principles of Balcı (1998) for all steps of our study.

Centeno and Reyes (1998) explain several concepts and techniques to analyze output of the simulation model. Kelton (1997) explain methods to help design the runs for simulation models and interpreting their outputs. Again, Kelton (1999) introduces some of the ideas, issues, challenges, and opportunities in deciding how to experiment with a simulation model to learn about its behavior. Montgomery (1992) explains design and analysis of experimental design in his book. We use these studies in output analysis and experimental design parts of our study.

Swisher and Jacobson (1999) presents a survey of the literature for two widely-used statistical methods for selecting the best design from among a finite set of k alternatives: ranking and selection and multiple comparison procedures. We use some of the methods stated in this study in evaluation of alternatives.

Takus and Profozich (1997) explain that the Arena software is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system. In our study, we use Arena software because of its desired properties.

2.3. Military Simulation

Hill, Miller and McIntyre (2001) describe the military as a big user of discrete event simulation models. They discuss the uses of military simulation and the issues associated with military simulation to include categorizations of various types of military simulation.

Garrabrants (1998) proposes an expansion of simulation system's role to support all levels of command and control functioning, especially staff planning after receipt of orders and mission rehearsal. He points out that simulation system is a natural solution to the commander's need for a planning and rehearsal system to support his operational planning efforts.

Smith (1998) identifies and explores the essential techniques for modern military training simulations. His study provides a brief historical introduction followed by discussions of system architecture, simulation interoperability, event and time management, verification and validation and fundamental principles in modeling and specific military domains.

Roland (1998) presents a panel of knowledgeable individuals who are filling those decision-making roles. Major problems in the current state of modeling and simulation development and use, major modeling and simulation opportunities and challenges are discussed in the panel “The future of military simulation”. He categorizes the military modeling and simulation as engineering models, analysis models and training models.

Chew and Sullivan (2000) discusses the activities and tasks during the early stages of model development and addresses each of the verification, validation and accreditation efforts separately, along with its associated activities. Balcı, Ormsby, Carr and Saadi (2000) provide guidance in developing and executing a comprehensive and detailed verification, validation and accreditation plan throughout the entire modeling and simulation application development life cycle. Hartley (1997) explains verification and validation in military simulations and discusses the cost aspect of verification and validation.

CHAPTER 3

The Simulation Model

3.1. Formulation of the Problem and Planning the Study

One of the most important aspects of simulation study is a careful statement of the objectives. Our main objective is to investigate how to increase border control and efficiency of border security along the borders of Turkey. We think that the use of simulation and statistical procedures analyzing the border security system will help to achieve our main objective. We have other objectives to achieve. These are: to make a thorough examination of the border security system structure and its components, observe the relationships between performance measures, analyze factors that effect the performance measures, find out the ways to increase the performance measures, and investigate system responses when changes made in the system or addition of resources made to the system to improve the performances.

As we already know, it is always preferable to use analytical models whenever possible. At first glance optimization models seem to be available for the modeling and solution of the system. But border security system has dynamic behavior that the system state changes over time. If we look from the point of performance measures, optimization model will give solution for only one performance measure that is the maximum length of border that could be under control with our resources one at a time. But our performance measures depend on time, moving characteristics of security elements and catching of illegal infiltrations that all these measures have stochastic features. As we mention in objective statement of our study, our objectives are mostly related with behavior examination of the border security system and its components. We also try to investigate a wide variety of "what if " questions about our system to improve the performance measures. Consequently, when we look from the aspects of border security system characteristics (i.e. dynamic behavior of system, stochastic features of events), performance measures to be evaluated and objectives that motivate us to make such a study, simulation is appropriate tool for our study.

The Border Security System Model is developed to:

- Make it possible for border security planners to model the responsibility terrain of border troops with different deployment, organization, terrain conditions and resources.
- Analyze performance of border troops along the borders in their responsibility terrain in terms of performance measures.
- Make it easy to find the strong and weak sides along the borders.
- Help to see the results of precautions that are taken for weak points or to increase the security in the responsibility terrain of troops.
- Display the effect of each type of security element on the performance measures and allow determining priority for drilling and maintenance.
- Perform new policies, changes of organization or deployment before conducting real decisions about the system.
- Perform cost management before conducting real investments.

By using this model, border security planners, border troop commanders can accurately and efficiently examine the behavior of the system; they can easily see the results of their precautions and use the model as a support of their decision-making process. We try to answer the following research questions:

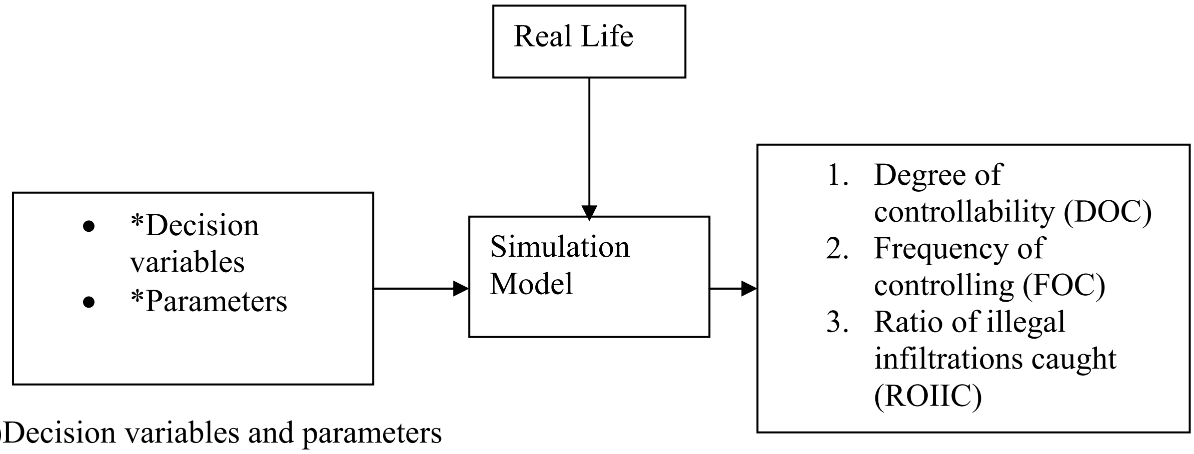
1. How efficient is the system if we consider the performance measures?
2. What are the relationships between security elements and performance measures?
3. What are the relationships between performance measures?
4. How much does each element effect performance measures?
5. What are the significant factors that affect the performance measures?
6. How much does it affect the system if coordination is established between security elements?
7. How much do additional resources affect the performance measures of the system?
8. Which parts of the border are strong and weak in terms of performance measures?

Explanation of Performance Measures:

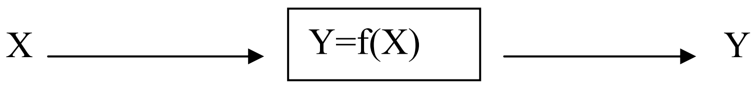
There are mainly three performance measures as an output of the system:

1. **Degree of Controllability (DOC)** is the ratio of time that a zone is under control by security elements in one-year time period. After it is calculated for each zone, the average of all zones is considered as a performance measure.
2. **Frequency of Controlling (FOC)** shows how many different times any zone gets under control by security elements in one-year time period. After it is calculated for each zone the average of all zones is taken as a performance measure.
3. **Ratio of Illegal Infiltrations Caught (ROIIC)** shows the ratio of number caught illegal infiltrations to the total number of caught and couldn't be caught infiltrations in one-year time period. The average of all zones is considered as a performance measure.

Input/Output Process



(*)Decision variables and parameters are given in Table 3.1 p.31.



Outputs of the model are the functions of random variables presented in Table 3.1. Among these random variables duty time of each security element, failures of high-tech devices, determination of duty places are the main random variables that affect the degree-of-controllability output whereas determination that patrols are motorized or on-foot and determination of mobile or stationary characteristics of duty are the main random variables that affect the frequency-of-controlling output. Arrivals of illegal infiltrations, infiltration time for each type of illegal infiltrations affect ratio-of-illegal-infiltrations-caught. But, the ratio-of-illegal-infiltrations-caught performance measure is also affected by random variables that affect the degree-of-controllability and the frequency-of-controlling performance measures. Briefly, when we consider the operational behavior of the border security system with its all components, each decision variable and parameter has an effect on each performance measure.

Other performance measures that the model is capable of evaluating:

- Number of illegal infiltrations caught by type (refugees, terrorists, smugglers, enemy special forces and enemy commando troops).
- Number of illegal infiltrations that couldn't be caught by type.
- Number of security elements (askarad, patrols, thermal camera, ambushes) that served during a year.
- Contributions of each security element to the system performance measures.

Data needs and stochastic factors are analyzed in the input data analysis section.

3.2. Model Development

First we develop a conceptual model of the system. At this stage, we determine the parts of real-world system to be modeled to achieve our objectives. If we think the border troops in real world, they have many activities other than border security. But all other activities support the main task that is protection and security of borders. Thus, our conceptual model is about the operational activities that border troops perform for security of borders. We model the operational activities of border company supported by border battalion. Based on this conceptual model, we then develop our logical and simulation model. Figure 3.1 shows the schematic view of border security system model development.

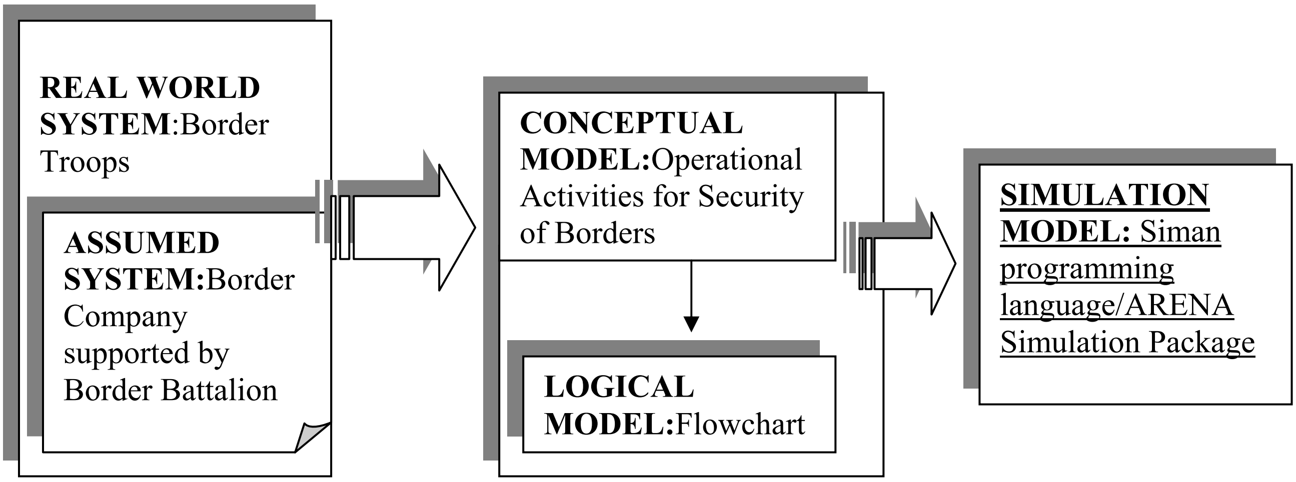


Figure 3.1. Schematic view of border security system model development

3.2.1. Conceptual Model

At this stage, we determine elements of system, their relationships, assumptions and data requirements of the simulation model.

Entities of the system:

- Patrols.
- Ambushes.
- Thermal camera.
- Askarad.
- Illegal infiltrations.
- Zones.

Attributes of the system:

- The departure time of security elements from their locations.
- Type of illegal infiltrations.

- Duty time for each security elements.
- Using of night-vision tools by ambushes.
- Patrol type.
- Moving or stationary characteristics of security elements.
- Security element type.

Events of the system:

- Departure of security elements from their locations.
- Arrivals of illegal infiltrations.
- Catching of illegal infiltrations.
- Changing places of duty for askarad, thermal camera and ambushes if they are moving.
- Failures before and during operation of askarad and thermal camera.
- Controlling of zones by patrols on their route.
- Controlling of zones by askarad, thermal camera and ambushes.
- Ending of duty and returning to locations.

Activities of the system:

- Controlling of zones by each security element.
- Illegal infiltrations.

Exogenous Variables (Input variables)

- Decision variables (controllable variables) and parameters (uncontrollable variables) are listed in the input data analysis section.

Endogenous Variables (Output variables):

State Variables:

- State of zones (under control or not).
- Number of illegal infiltrations caught for each type.
- Number of security elements in the system.

Performance measures:

- Degree of controllability.
- Frequency of controlling.
- Ratio of illegal infiltrations caught.

The assumptions of our model are:

- The system is considered under night conditions.
- The responsibility terrain of a typical border company is considered.
- There are four platoons directed by border company.
- Each border platoon has approximately 4-6 kilometers responsibility terrain.
- There is one thermal camera belonging to border company.
- There is one askarad belonging to border battalion and it serves to three border companies. Askarad is under consideration when it comes to responsibility terrain of border company that is in the model.
- Two of border platoons have capability of patrolling for two sides of its location. Two of them have capability for one side.
- There is no intelligence of any infiltration.
- Each zone is considered as an area that can be controlled by patrol.

Night conditions vs. day conditions

We model the border security system under night conditions. Because, most of the operational activities of border troops are performed under night conditions. Electronic surveillance systems (askarad, thermal camera), ambushes equipped with night-vision tools and patrols are the main security elements used for border control under night conditions. On the other hand, sentries and patrols under day conditions perform border control. Since the visibility is high under day conditions, sentries stationed at watchtowers control wide part of border. Therefore, control of border under day conditions is too high. Moreover, illegal infiltrations (terrorists, smugglers, refugees and enemy forces) try to infiltrate under night conditions. Because, they want to take the advantage of poor visibility of night not to be caught by our security elements. To prevent illegal infiltrations along the border, active precautions are taken under night conditions. This is possible only by using technology and personnel (askarad, thermal camera, ambushes and patrols) more frequently under night conditions. Thus, the real border security system operates under night conditions with its all components. This is why we model the system under night conditions rather than day conditions.

System is non-terminating system since there is no event that determines the end of simulation run-length. Hence, we perform steady-state simulation. We will explain determination of run-length of the simulation in Chapter 4.

3.2.2. Logical Model (Flowchart Model of the System)

By examining the relationship among elements, we construct our logical model. It starts with departure of security elements from their locations and ends with returning to their start locations. At the same time, the arrivals of illegal infiltrations are considered. The relations between these entities and events are modeled and presented in Figures 3.2-3.7 as flowcharts. In Figure 3.2 departure of security elements from their locations by type and arrivals of illegal infiltrations are presented and they are labeled by numbers to which logical model they follow. The rest of the Figure 3.2 is the general flowchart model of the system. Security elements leave their locations for duty according to weather conditions and failure conditions of high-tech devices. Meanwhile, type of duty (stationary or moving) and duty places are determined. Then, since there are four security elements, their relations according to existence of another element in the zone or arriving of any security element while another one is in that zone are presented. Again, we use labels to determine the rest of the logical flow that security elements and illegal infiltrations follow when they meet with such a situation. At last, if security elements complete their duty, they go back to their locations and if not, new duty places are determined and they go on duty. This continues until security element completes its duty. Figures 3.3-3.6 present flowcharts of askarad, thermal camera, ambushes and patrols sequentially. Figure 3.7 presents flowchart of illegal infiltrations.

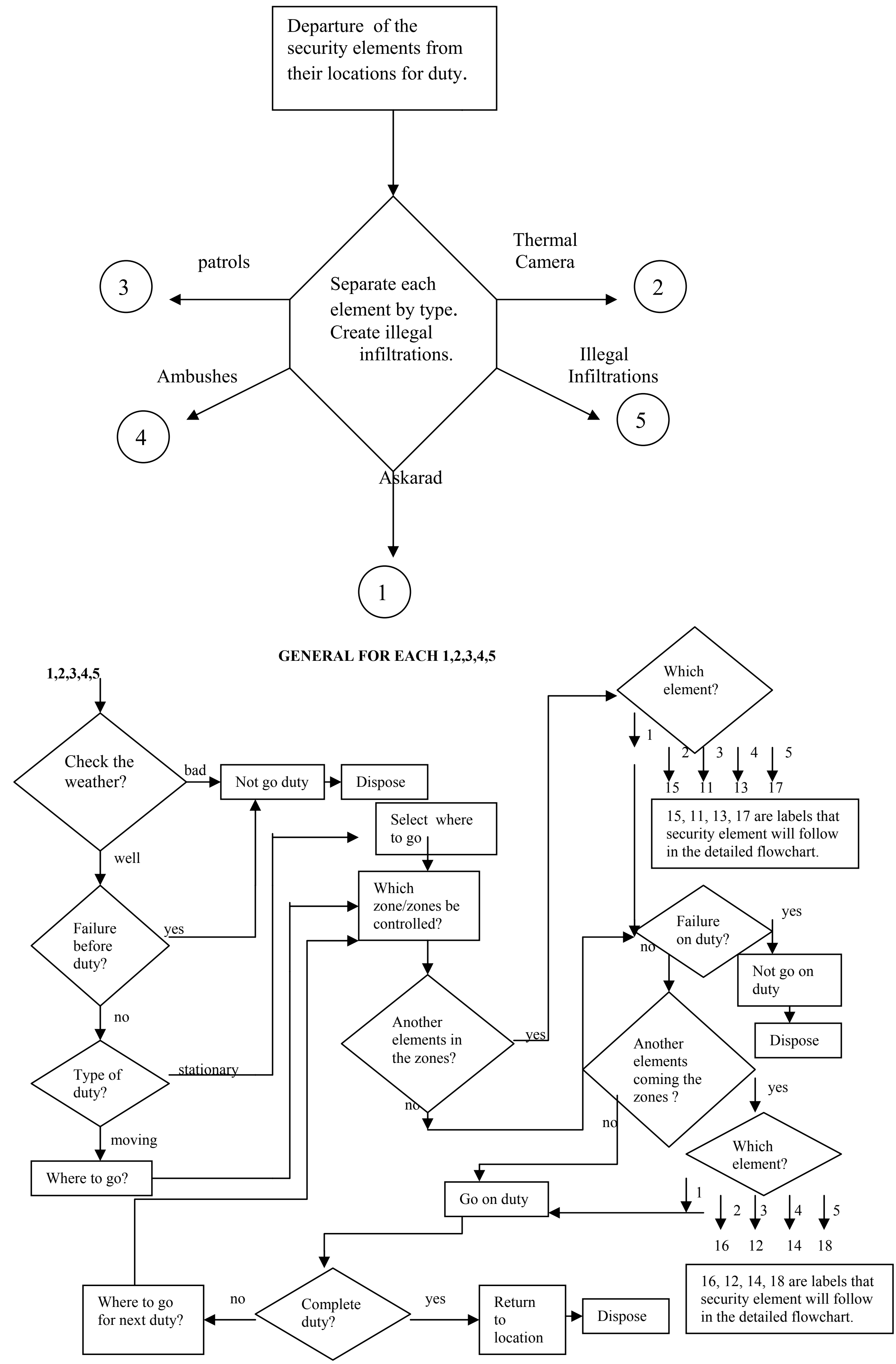


Figure 3.2. The General Flowchart of the Logical Model

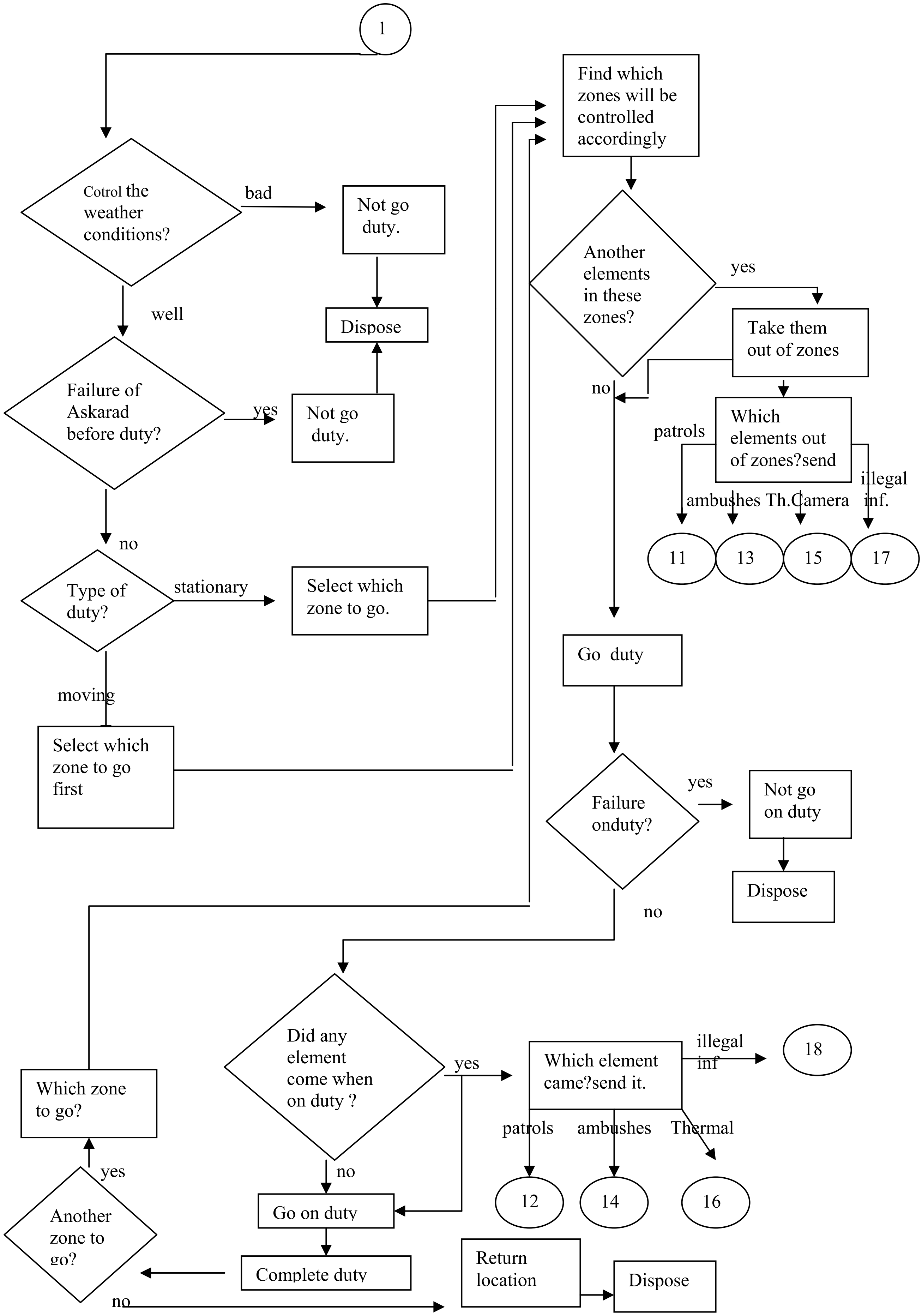


Figure 3.3. The Flowchart of Askarad

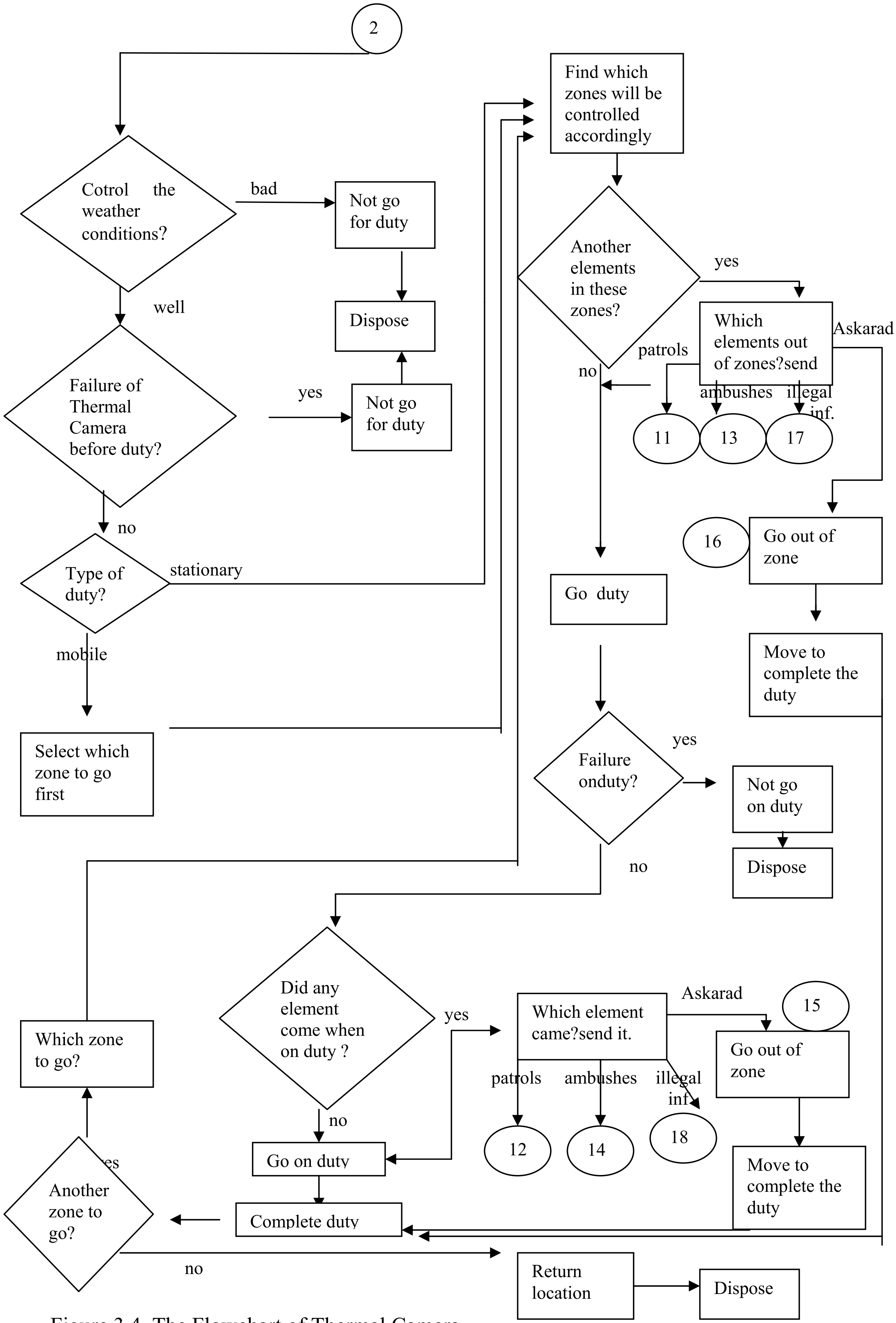


Figure 3.4. The Flowchart of Thermal Camera

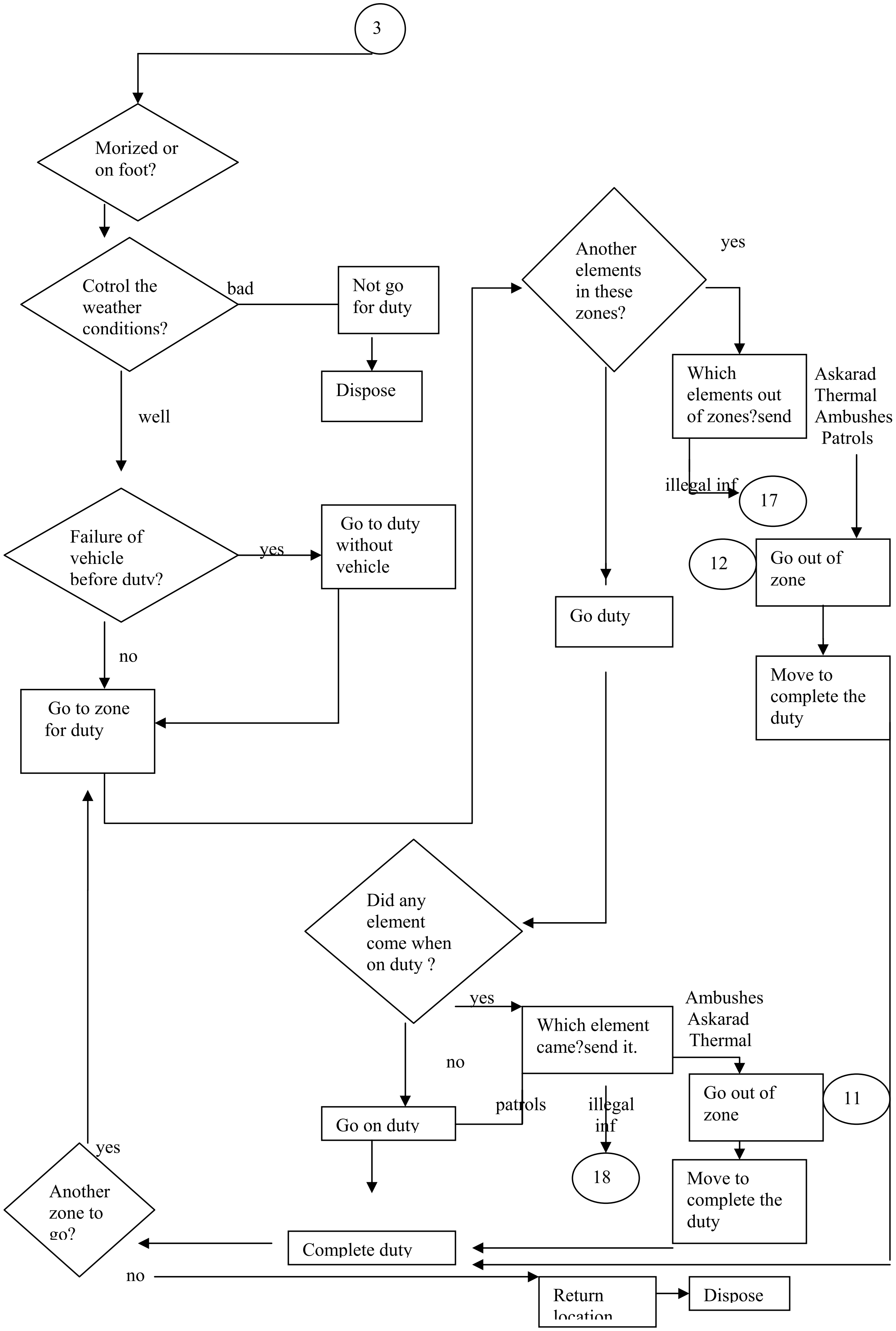


Figure 3.5. The Flowchart of Patrols

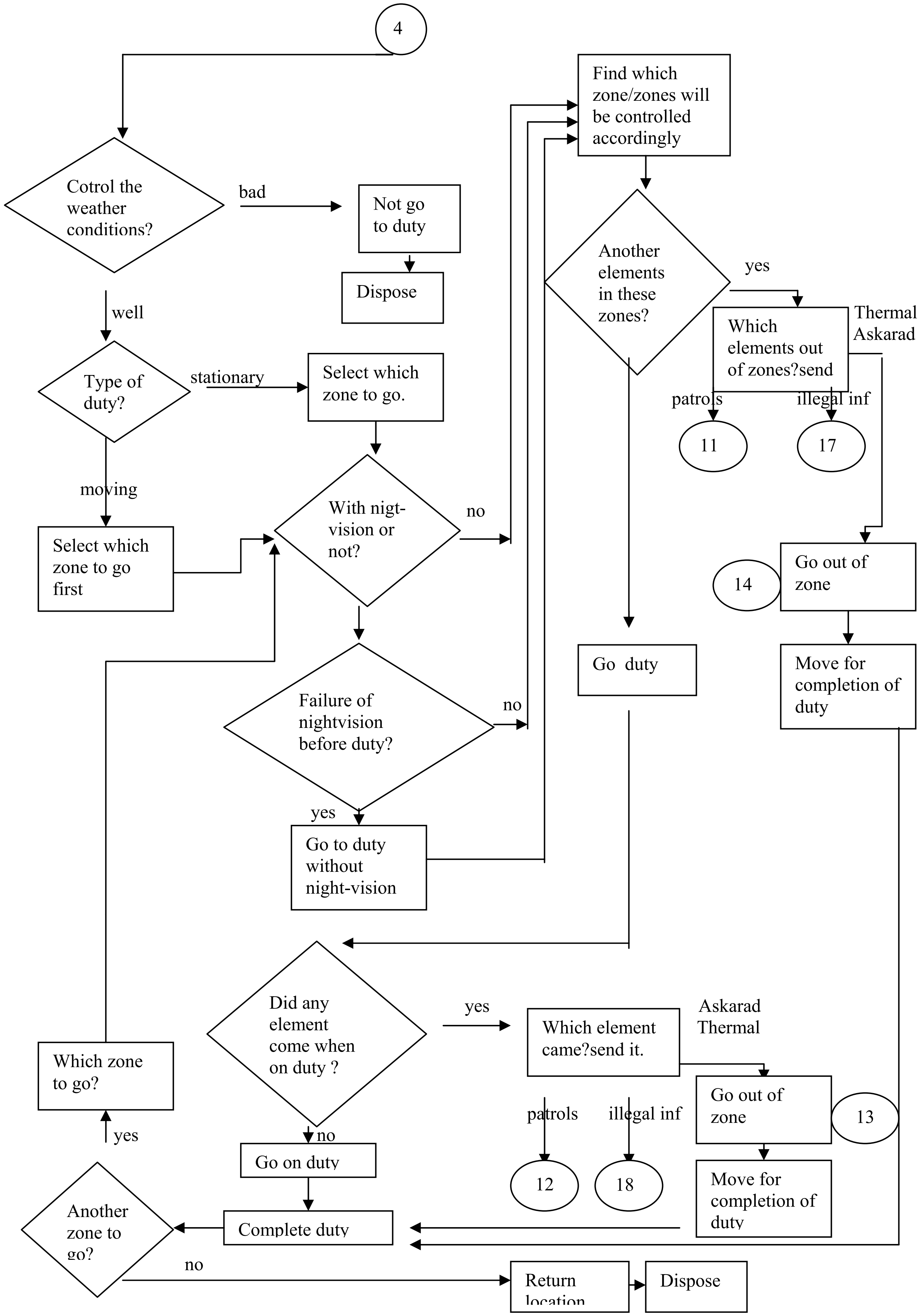


Figure 3.6. The Flowchart of Ambushes

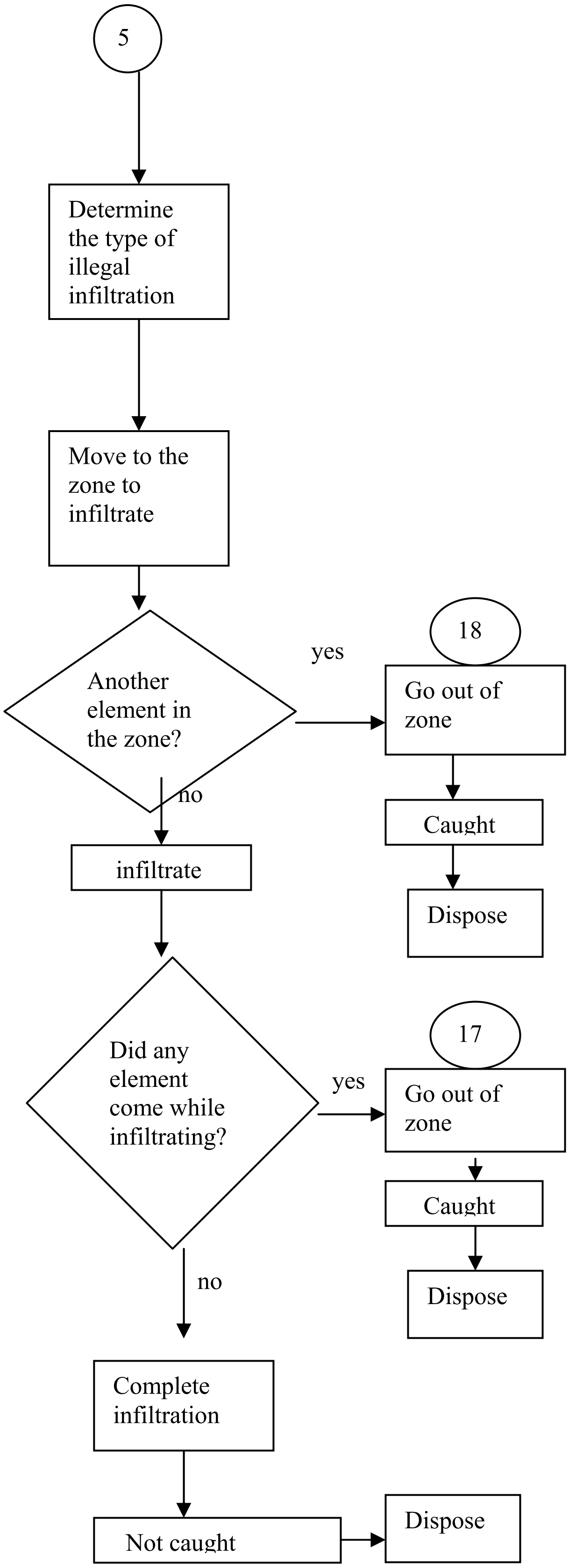


Figure 3.7. The Flowchart of Illegal Infiltrations

3.2.3. Simulation Model (Computer Code)

Border troops are like factories that production is security service provided for borders. In other words, border troops produce security service along the land borders of our country. Border security system differs from typical manufacturing systems since it does not contain queuing models or the production of the system is not material. Although, when we consider some aspects it differs, we can handle the border security system as a mixture of manufacturing and military systems. We know that Arena software is very popular manufacturing simulation software with its flexible usage. Therefore, we use Arena software. It is useful to model border security system with its flexibility beyond it is a well-known manufacturing system simulation software and it gives a wide opportunities to evaluate the system performances under different conditions. The computer codes occupy 6.81 MB without animation, the animation at a level of border platoon 9.46 MB and the animation of border company 8.44 MB. We animate all details at a level of border platoon. One run without animation takes approximately 55 seconds. We present some parts of the codes of model in Appendix F.

3.3. Input Data Analysis

There are several random variables in the model. These variables and their distribution functions are given in Table 3.1. The parameters of these distribution functions can be found in Appendix G. In Appendix G, the detailed explanation about input data is also presented. In general, we use data taken from army field manuals and established statistics that gained by experiences. The controllable and uncontrollable variables of the model are seen in Table 3.1 too. The ones signed with check are controllable variables and the others are uncontrollable variables of the model.

Table 3.1. Random variables and their distribution functions

Random Variables	Distribution Functions	Table numbers that contain parameters
arrivals of illegal infiltrations.	exponential	G.1
type of illegal infiltrations.	discrete	G.2
infiltration time for each type of illegal infiltration.	triangular	G.3
✓ duty time of patrols (according to motorized or on-foot)	triangular	G.4
duty time of ambush, thermal camera and askarad (according to stationary or mobile).	triangular	G.5
duty time when failure occurred.	uniform	G.6
weather conditions.	discrete	G.7
failures before duty.	discrete	G.8
✓ determination of mobile or stationary characteristics of duty.	discrete	G.9
✓ determination that patrols are motorized or on-foot (for each platoon).	discrete	G.10
✓ determination that ambushes with night vision device or not.	discrete	G.11
✓ the degree of use of high-tech devices.	discrete	G.12
determination of which zone ambush will go first (for each platoon).	discrete	G.13a-13d
determination of which zone thermal camera will go first.	discrete	G.14
determination of which zone askarad will go first.	discrete	G.15
determination of which zone will thermal go, if it has mobile characteristic after end of duty at any zone.	discrete	G.16
determination of which zone will askarad go, if it has mobile characteristic after end of duty at any zone.	discrete	G.17
determination of which zone will ambush go, if it has mobile characteristic after end of duty at any zone.	discrete	G.18a-18p

3.4. Model Verification and Validation

Verification and validation phase is vital for any simulation study. Because any conclusions derived from the model that is not verified and validated will be doubtful. We verify and validate our model by using some techniques and considering the principles of Balcı (1998) for all steps of our study.

3.4.1. Verification of Model

Verification is determining that a simulation computer program performs as intended. In other words, by using verification techniques we will check the translation of the conceptual model into a correctly working program.

- **Tracing:** By using Arena trace option, we can observe the state of our model. The state variables, statistical counters are printed out just after each event occurs. Thus, we can easily check if the program is operating as intended.
- **Writing and Debugging in Modules and Subprograms:** Border security system model contains four border platoons. Each border platoon means different subprograms. We check the code while developing each subprogram and find location of errors easily in the code and correct. Then we add levels of detail and check them until the model accurately represents the system.
- **Running Under Variety of Input Parameters:** We take a lot of simulation experiments by changing input parameters in Chapter 4. We see that the outputs are reasonable. Because outputs of the model are as expected.
- **Animation:** We develop animation to observe the movements and states of entities in our model. We develop two kinds of animation; one is with using all

entities for border platoon and the other one is with using states of zones for border company.

3.4.2. Validation of Model

By validating our model we can see that the proposed model for border security system is really the accurate representation of the real system. Only after the model is validated the evaluations made with the model can be credible and correct. We use some techniques to validate our model. In addition, when we examine the results of experiments presented in next chapters, we see that our model gives reasonable results that show the model is valid.

- **Fault/Failure insertion test:** This test is used to observe the output of the model when a fault (incorrect model component) or a failure (incorrect behavior of a model component) is inserted into the model. If the model produces the invalid behavior as expected we can say that our model is valid. First, we insert a new security element that behaves like thermal camera into the system (incorrect model component). But interarrival time of beginning to duty of this new security element is shorter than typical interarrival time of thermal camera. Then, we observe the results as seen in Figure 3.8. The degree of controllability is estimated 80% instead of expected 25%. The model produces the invalid behavior as expected. Secondly, we change the behavior of thermal camera and askarad as they go only one place and control the areas that can be controlled from that place (incorrect behavior of a model component). Then, we observe the results as seen in Figure 3.9. The degree of controllability differs about 30% between zones that askarad and thermal camera go and not go. We conclude that the model produces the invalid behavior as expected; that is we can say that our model is valid.

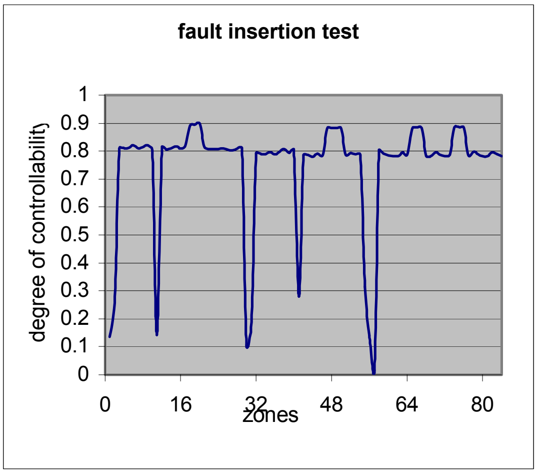


Figure 3.8. Fault Insertion Test

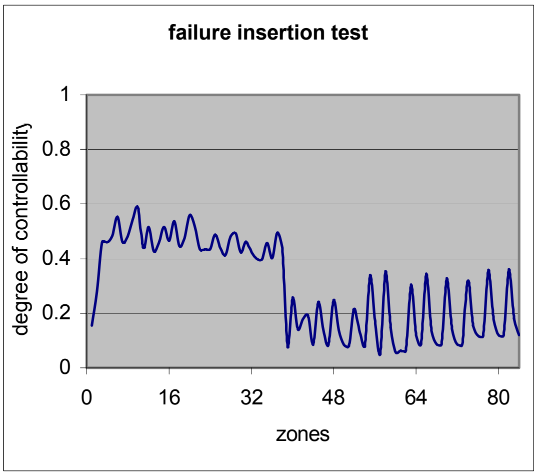


Figure 3.9. Failure Insertion Test

- **Comparison of Simulation results and calculations made by hand:** We calculate degree of controllability of one zone from each of the border platoons by using input data. Then we compare these results with ones we obtain from the simulation model. Figure 3.10 shows the comparison. The results we obtain from simulation model are smaller than calculations made by hand for all zones due to overlaps. In the real system, the zones can be controlled by different security elements at the same time and when the simulation model meets such a situation it takes into account only one of the security elements but when we calculate by hand we cannot consider such a situation. As a result, it is reasonable that simulation results are a bit smaller and it is more valid than calculations made by hand since simulation model takes overlaps into account.

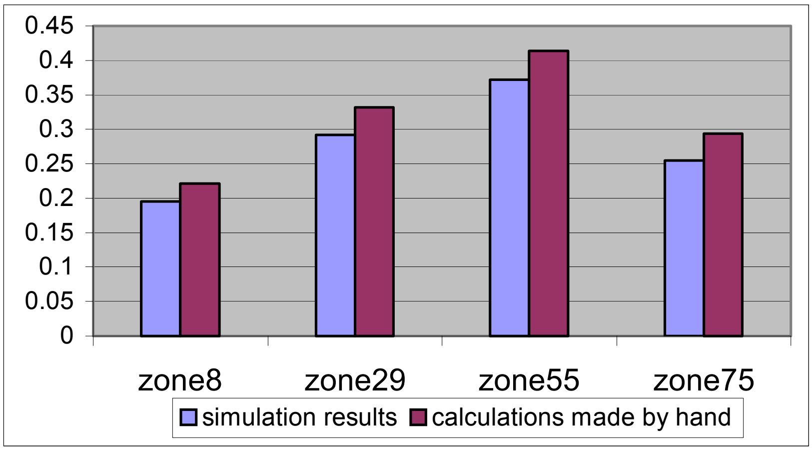
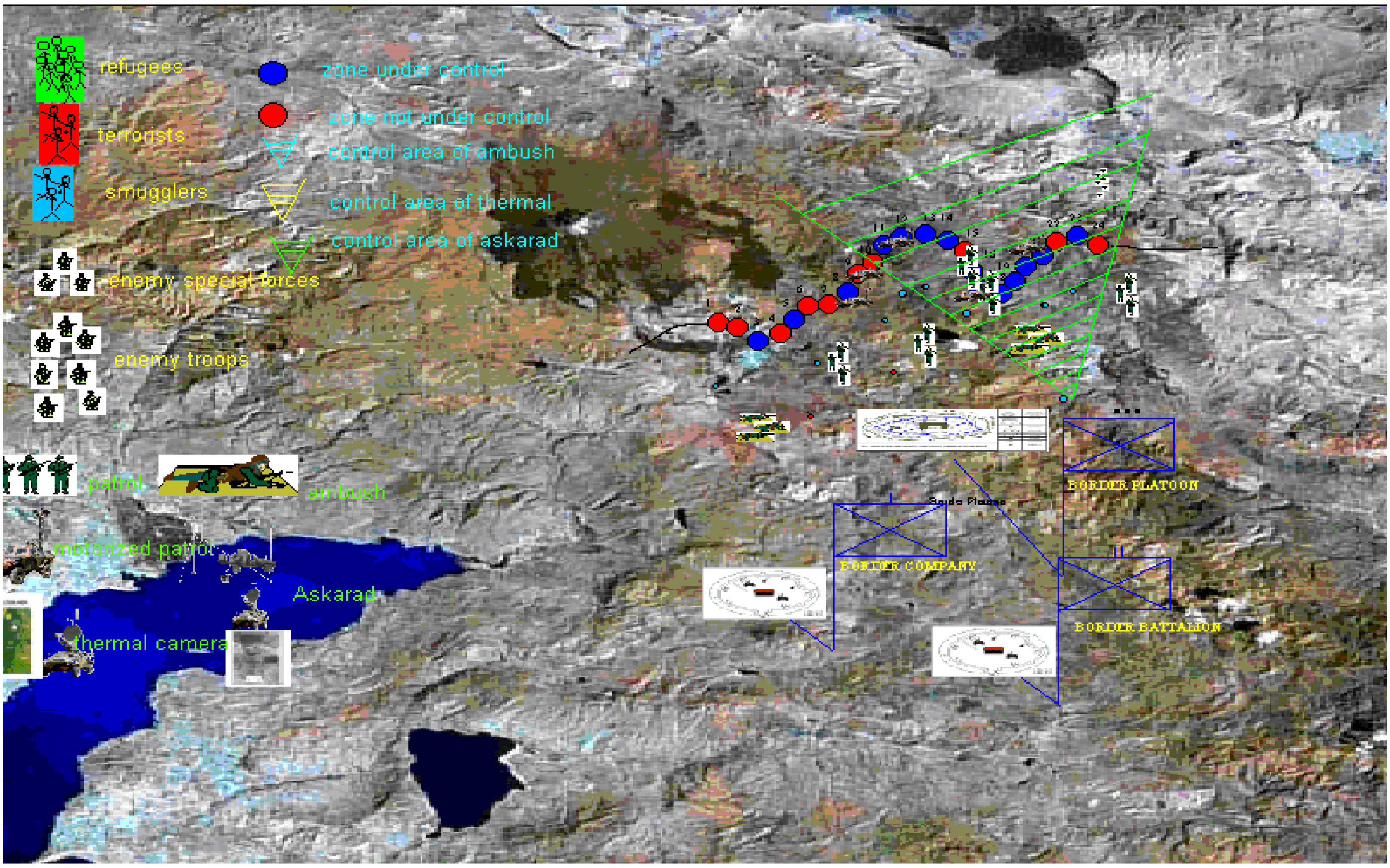


Figure 3.10. Comparison of Simulation Model Results and Calculations made by hand

- **Sensitivity Analysis:** This technique is performed by systematically changing the values of model input variables and parameters over some range of interest and observing the effect upon model behavior. Unexpected effects may reveal invalidity. We conduct a number of experiments by changing input variables; when we investigate the behavior of the system, find out the relations of system components and contribution of each security elements to the system in Chapter 4. We present many graphics and constructed confidence intervals there. In these experiments we don't meet any unexpected effect of input variables on outputs. Even, all the results are reasonable as expected.

- **Visualization and Animation:** Since we have animation of the model, we can easily observe the behavior of the system. We can conclude that the system is modeled as in the real life. A sight of animation of the simulation model is given in Figure 3.11.



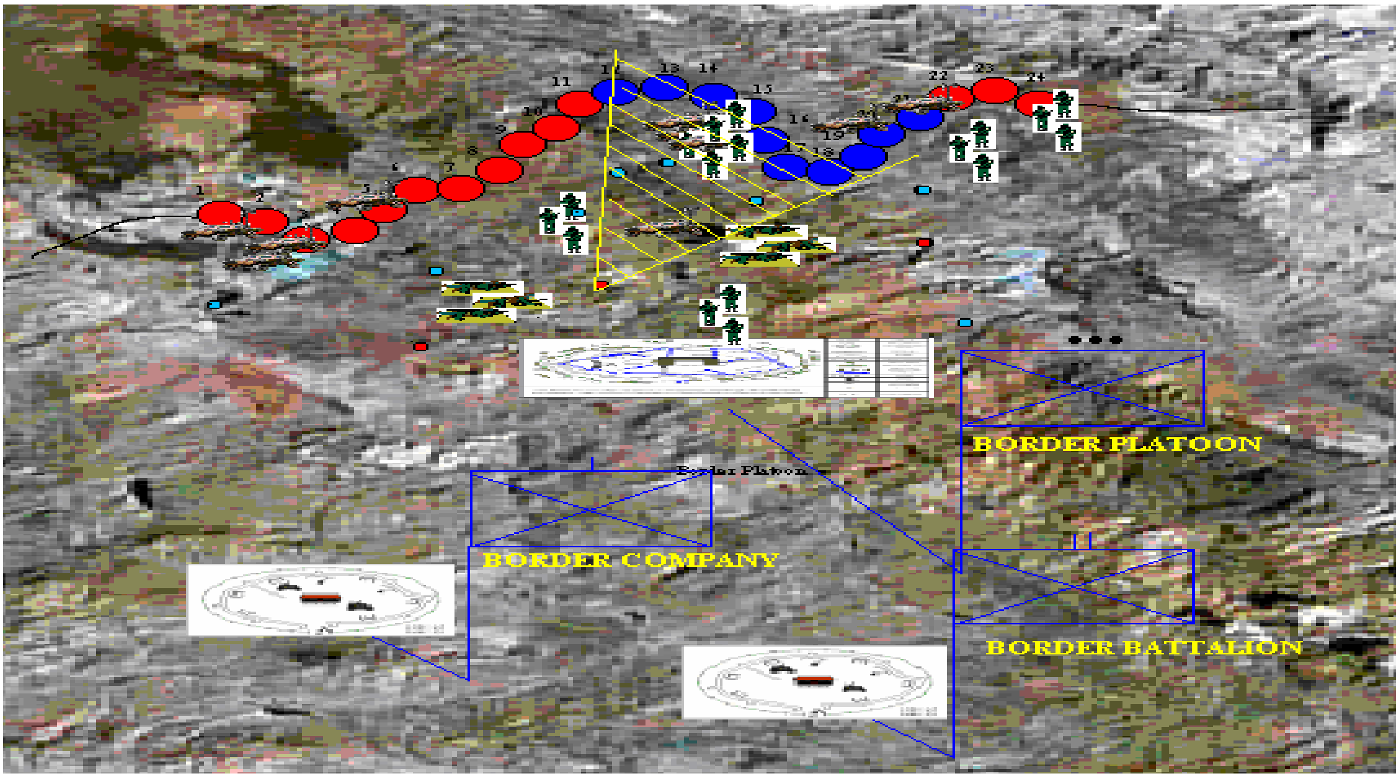


Figure 3.11. A Sight of Animation of the Simulation Model

CHAPTER 4

Experimentation and Output Data Analysis

4.1. Determination of Run-length and Number of Replications

To obtain accurate results from the simulation model we have to determine appropriate sample sizes by adjusting simulation run-length and/or determining the number of replications. In general, half-length of a confidence interval constructed around the estimator is used as a measure of accuracy. To achieve the desired accuracy, we first run the simulation model with five replications for different run-lengths. Here we use degree-of-controllability as an output variable or performance measure. Then, we calculate point and interval estimators (i.e., mean and confidence interval). We note that half-length as an indicator of accuracy is different for different zones (some of them are narrow, some of them are wide). Since our aim is to achieve the desired accuracy in the worst-case situation, we decide to use the half- length of a zone, which is maximum out of all the zones for a given run-length. Figure 4.1 presents the results for various run-lengths. As seen in this figure, for example, zone 78 has the maximum half-length for the simulation run-length of one-week whereas zone 37 has the maximum half-length (least accuracy) for 3-year simulation run-length. Note that the curve gets flat after 6-month of run-length, this means that variance of the estimator stabilizes after certain number of observations in the output data. We obtain the desired precision and confidence levels from the experts of the system. In Table 4.1, desired precisions are presented for each performance measure.

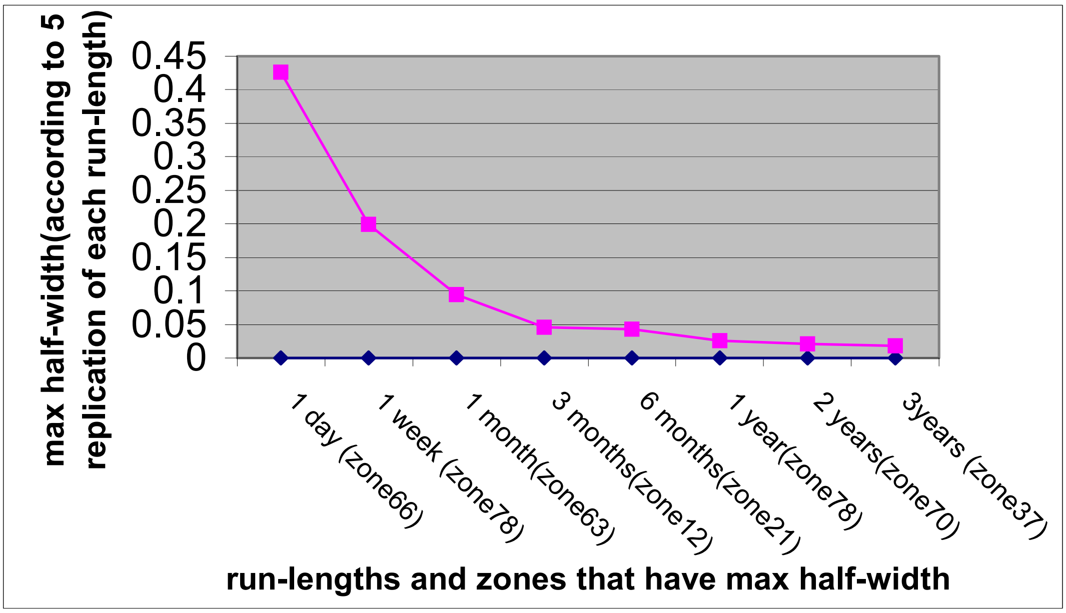


Figure 4.1. Determination of run-length for degree of controllability

Table 4.1. Desired precisions

Performance measure / Desired precision	Degree of controllability	Frequency of controlling	Ratio of illegal infiltrations caught
Absolute precision	0.02	0.025	100
Relative precision	10%	5%	5%

Then, we calculate number of replications required to obtain an absolute precision 0.02 (approximately 10% relative precision) for different simulation run-lengths, starting from 6-month run-length for degree of controllability. To determine sample sizes, we use two-stage procedure suggested by Law and Kelton (1991). Table 4.2 presents the two-stage procedure results. Based on these results, we conclude that 1-year run-length and 10 replications is enough to achieve desired accuracy. One-year run-length is selected because 6-month run-length requires excessive simulation replications (e.g. 23 runs). On the other hand, 2 and 3-year run-lengths need approximately same number of replications with 1-year run-length, but they need 2 and 3 times more of computer time. Hence, we decided to set the run-length to 1 year and the number of replications to 10 for the degree-of-controllability performance measure.

When the same procedure is applied for other performance measures, we observe that 4 replications are enough for the ratio-of-illegal-infiltrations-caught measure and 2 replications for the frequency-of-controlling to obtain desired accuracy. However, to be on the conservative side, we decided to take maximum of these replications for the rest of the study (i.e., 1 year run-length and 10 replications).

Using the sample sizes determined above, we run the simulation model and calculate the point and interval estimators for each performance measure at various confidence levels, e.g., 90%, 95%, and 99%. The results are presented for border company and for each border platoon in Appendix A (Tables A.1a-A.1c, A.3a-A.5d). When the half-length of these confidence intervals are examined, it is observed that absolute and relative precision for each performance measure are satisfied (see p.95).

Table 4.2. Results of Two-stage Procedure

Run-length	$i \geq s^2(n)\left[Z_{1-\frac{\alpha}{2}} / \beta\right]^2$ # of replications according to 1st stage calculations for β=0.02 and α=0.05	$n^*_a(\beta) = \min\{i \geq n : t_{i-1,1-\frac{\alpha}{2}}\sqrt{\frac{s^2(n)}{i}} \leq \beta\}$ # of replications according to 2nd stage calculations for β = 0.02 and α = 0.05
6 months	20	23
1 year	8	10
2 years	5	8
3 years	4	6

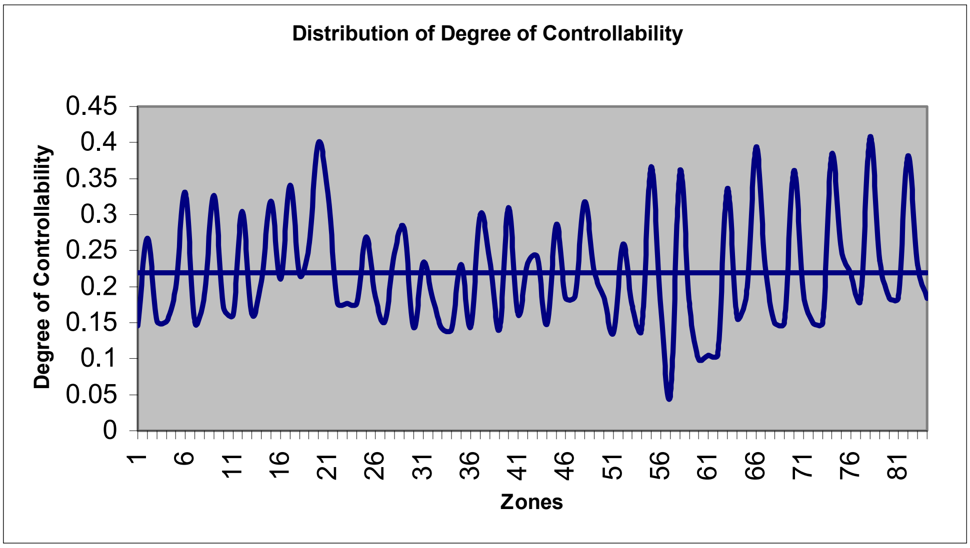
4.2. Output Analysis of the System

Having the simulation model developed, verified, validated and appropriate sample sizes determined, we analyze the system for each performance measure. Specifically, we examine the behavior of the system, find out the relationships between performance measures and security elements, and determine the weak and strong sides of the system. We also identify the relationships between performance measures and investigate effects of each security element on each performance measure.

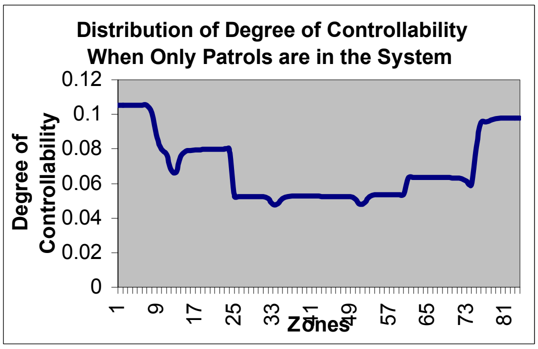
4.2.1. Analysis of Degree of Controllability Performance Measure

Recall that degree of controllability (DOC) is the ratio of time that a zone is under control by security elements (patrol, ambush, thermal camera, askarad) in one year time period. The results of the simulation experiments for DOC are given in Figure 4.2. As seen in Figure 4.2a, some of the zones have higher degree of controllability and some of them have less. It means that our control is not uniform along the border. This is due to the different use of security elements in the different zones. This highly volatile behavior has the mean of 0.2199. The confidence intervals constructed for 90%, 95%, and 99% are given in Appendix A (Table A.2a and Tables A.6a-A.6d) for border company and for each border platoon. In our study the zones between 1-24, 25-42, 43-60, 61-84 are in the responsibility terrain of 1^{st}, 2^{nd}, 3^{rd} and 4^{th} platoons, respectively.

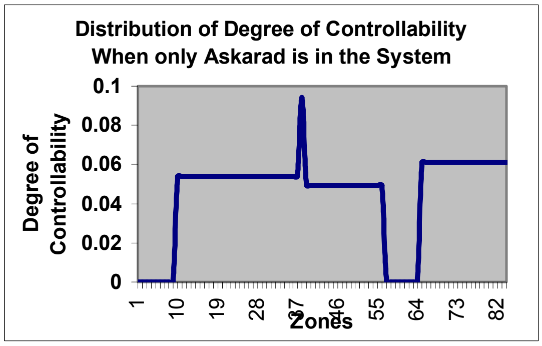
To explain the behavior of DOC, we also run the simulation model when only one of the security elements is in the system. The distributions of DOC when only one of the security elements is present in the system are given in Figures 4.2b-4.2e. Ambush has the most variability for DOC, since they are used only in the critical zones, whereas patrols have the least variability due to the fact that they are used unifomly along the



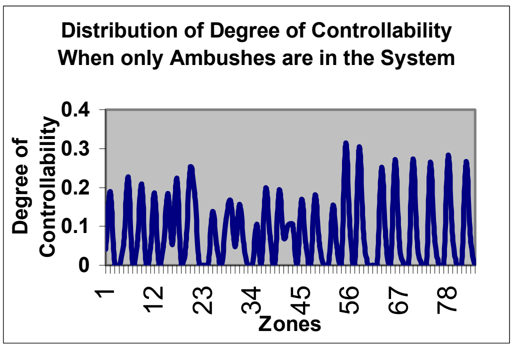
a) Distribution of Degree of Controllability (all security elements are in the system)



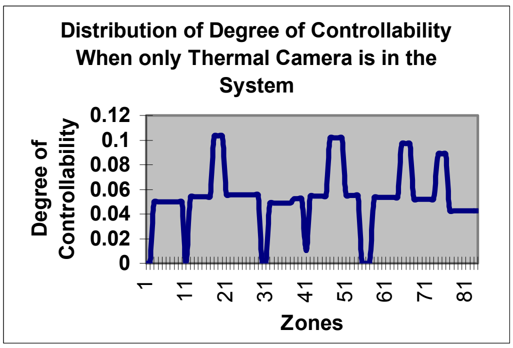
b) Distribution of DOC
(Only patrols in system)



c) Distribution of DOC
(Only askarad in system)



d) Distribution of DOC
(Only ambushes in system)



e) Distribution of DOC
(Only thermal camera in system)

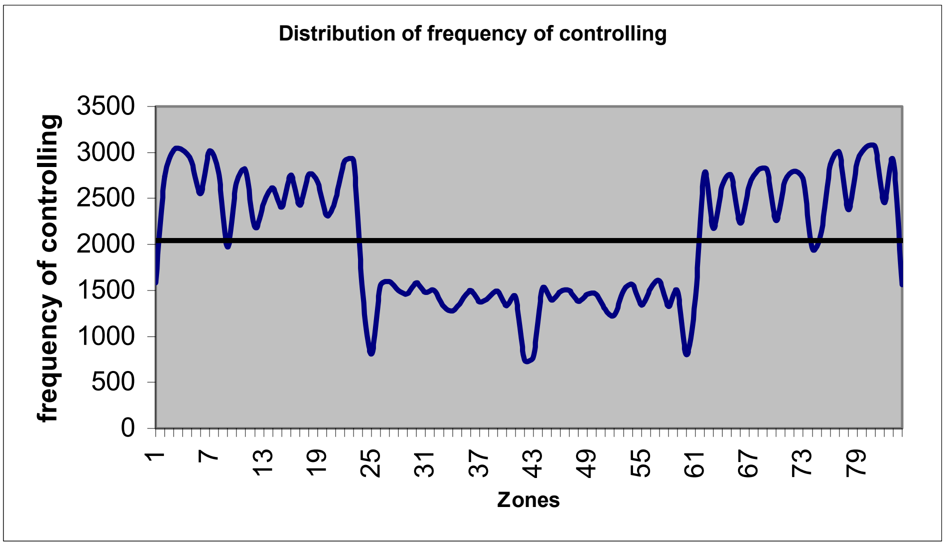
Figure 4.2. Distribution of degree of controllability

borders. Note also that the behavior of thermal camera and askarad (in terms of variability) is somewhere in between ambush and patrols. Because, thermal camera and askarad, for example, once they are located on their duty places, they provide the security service for wider zones. The overall effects of all security elements are seen in Figure 4.2a. Note that the DOC measure is mostly affected by the ambushes.

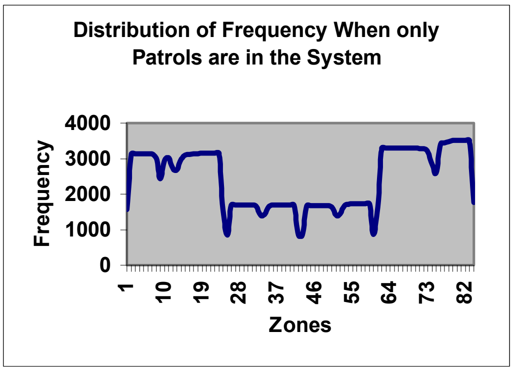
Moreover, Figure 4.2 displays the weak and the strong sides of the security system along the border. Once the weak sides are identified commanders take necessary precautions to improve the level of security. For example, 57th zone seems to be the weakest zone in our system. This is due to the fact that only patrols give the security service to this zone. Thus, other security elements should be selected for this zone to improve DOC.

4.2.2. Analysis of Frequency of Controlling Performance Measure

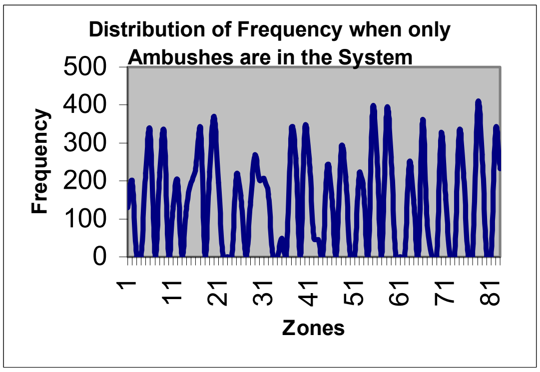
Recall that frequency-of-controlling (FOC) shows how many different times any zone gets under control by security elements (patrol, ambush, thermal camera, askarad) in one year time period. The results of the simulation experiments for FOC are given in Figure 4.3. As seen in Figure 4.3a, distribution of FOC is not uniform along the border. This behavior is due to the different mobility characteristics of each security element. We also observe that the zones between 25 and 60 have less FOC with respect to other zones. This difference is due to the different capacity of patrol. 1^{st} and 4^{th} platoons have capacity of patrol for two sides whereas 2^{nd} and 3^{rd} platoons for one side. The FOC has the mean of 2025. The confidence intervals constructed for 90%, 95%, and 99% are given in Appendix A (Table A.2b and Tables A.7a-A.7d) for border company and for each border platoon.



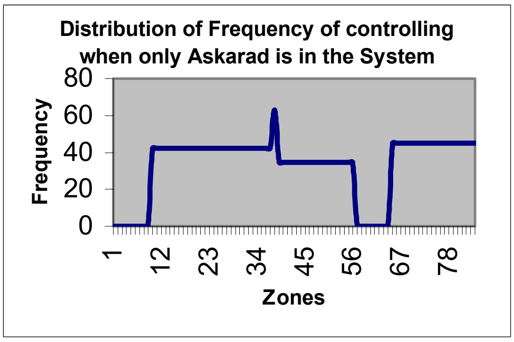
a.) Distribution of Frequency of Controlling (all security elements in the system)



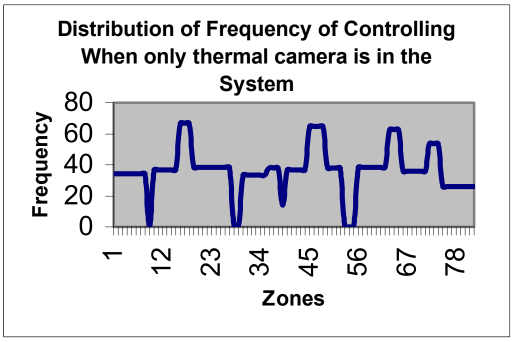
b) Distribution of FOC
(Only patrols in system)



c) Distribution of FOC
(Only ambushes in system)



d) Distribution of FOC
(Only askarad in system)



e) Distribution of FOC
(Only thermal camera in system)

Figure 4.3 Distribution of Frequency of Controlling

To explain the behavior of FOC, we also run the simulation model when only one of the security elements is in the system. The distributions of FOC when only one of the security elements is present in the system are given in Figures 4.3b-4.3e. We notice that the shape of distribution of FOC in Figure 4.3a and the shape of distribution of FOC when only patrols are in the system in Figure 4.3b are very similar to each other. This shows us that the most mobile security element in the system is patrols. We also observe from Figure 4.3b that the zones in the responsibility terrain of 2nd and 3rd platoons have significantly less FOC due to the capacity of patrol to one side. Patrols have the least variability due to the fact that they are used uniformly along the borders whereas ambush has the most variability for FOC, since they are used only in the critical zones. Unlike for DOC, FOC is less for the zones where ambushes get under control. Because, if a zone is under control for a long time (a zone can be under control throughout the night by ambushes, thermal camera and askarad) then FOC doesn't occur during this time period. It shows us that FOC is less for the zones that DOC is at high level. The overall effects of all security elements are seen in Figure 4.3a. Note that the FOC measure along the borderline is mostly affected by the patrols.

Moreover, Figure 4.3 displays the weak and the strong sides of the security system along the borderlines. Once the weak sides are identified commanders take necessary precautions to improve the level of security. For example, the zones between 24 and 60 seem to be the weak zones in our system. This is due to the fact that capacity of patrol to one side. Thus, precautions should be taken to increase the capacity of patrol or mobility of patrols between these zones to improve FOC.

4.2.3. Analysis of Ratio of Illegal Infiltrations Caught Performance Measure.

Recall that ratio-of-illegal-infiltration-caught (ROIIC) is the ratio of number of caught illegal infiltrations to the total number of caught and couldn't be caught infiltrations in one year time period. The results of the simulation experiments for ROIIC are given in Figure 4.4. As seen in Figure 4.4 distribution of ROIIC is not uniform along the border. The shape of distribution of ROIIC reminds us the shape of distribution of FOC due to weakness between zones 25 and 60. When we compare distributions of DOC and ROIIC, we notice that ROIIC is less where DOC is less and vice-versa. These observations bring mind a question whether there are relationships between DOC, FOC and ROIIC. We analyze these relationships in detail in Section 4.2.4. The ROIIC has the mean of 0.5307. The confidence intervals constructed for 90%, 95%, and 99% are given in Appendix A (Table A.2c and Tables A.8a-A.8d) for border company and for each border platoon.

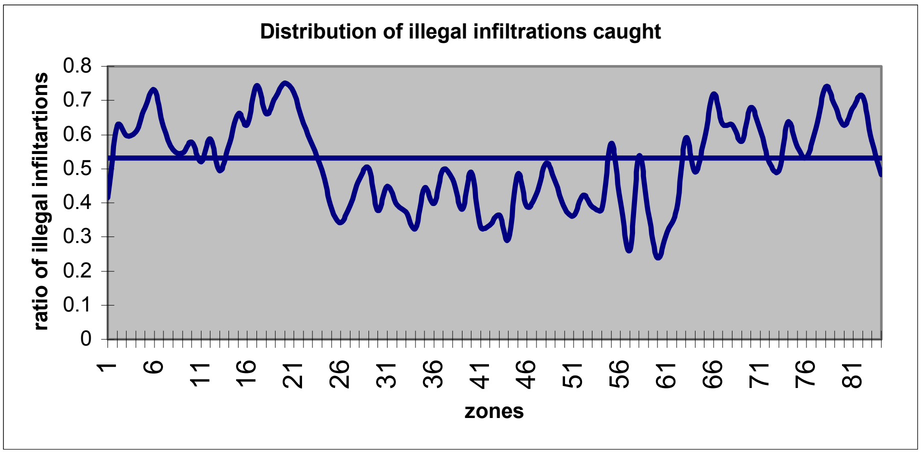
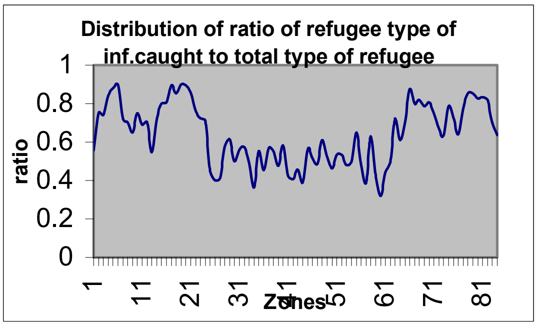
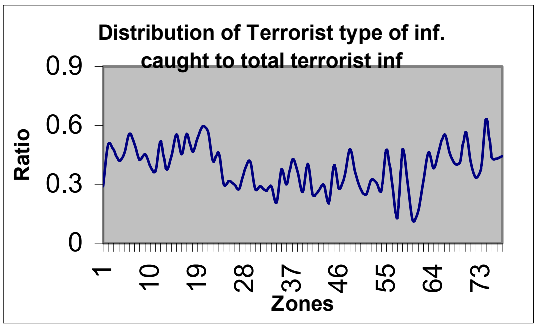


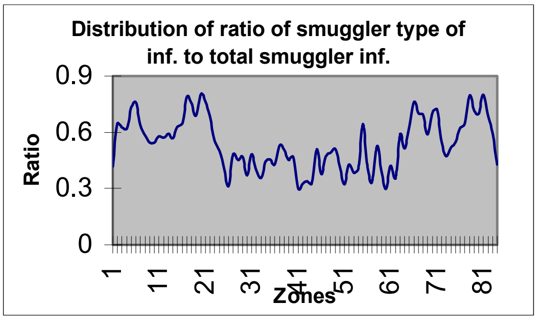
Figure 4.4. Distribution of Ratio of Illegal Infiltrations Caught



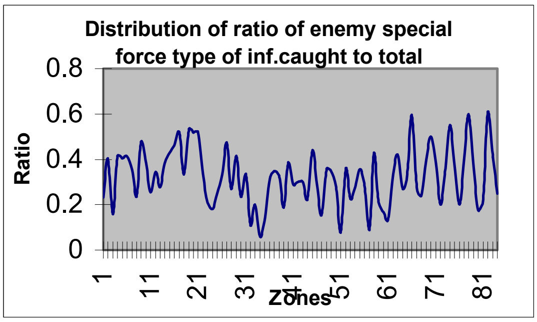
a) Distribution of refugee



b) Distribution of terrorist



c) Distribution of smuggler



d) Distribution of enemy special

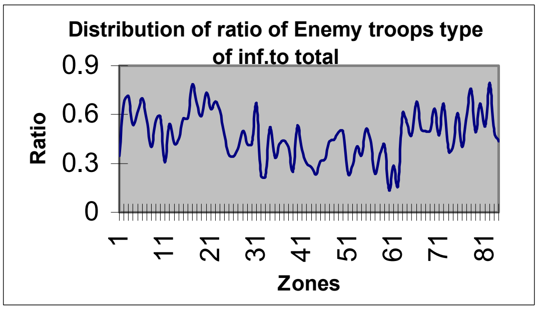
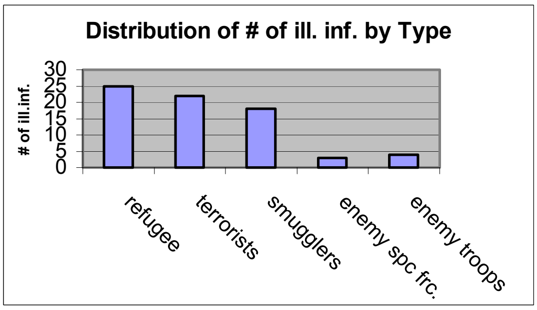
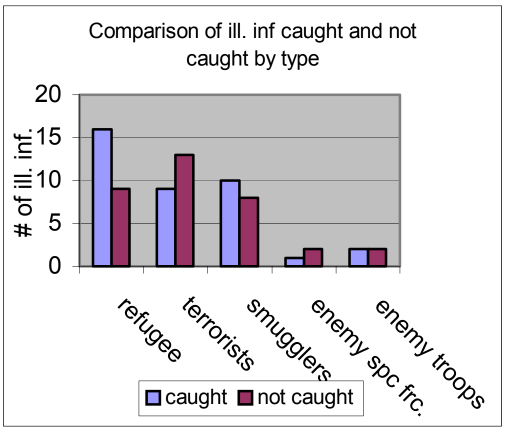
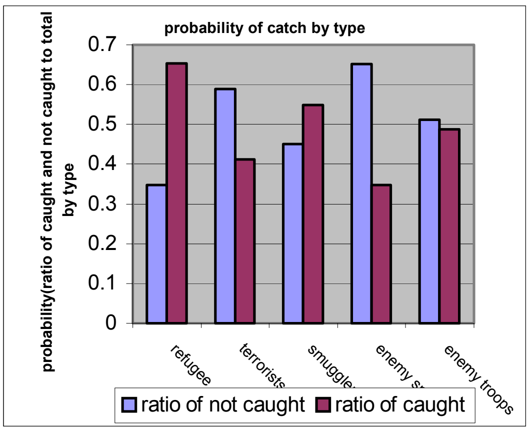


Figure 4.5e. Distribution of enemy troops



f) Distribution of ill.inf. by type





g) Comparison of caught and not caught by type h) Probability of catch by type
Figure 4.5 Distribution of Ratio of Illegal Infiltrations Caught

The distributions of ROIIC for each type of illegal infiltration (refugee, terrorist, smuggler, enemy special force and enemy troops) are presented in Figures 4.5a-4.5e. As seen in these figures, for example, ROIIC is around 0.6 for refugee type of infiltrations whereas 0.2 for enemy special force type of infiltrations. Because, infiltration time varies for each type of infiltration. Terrorists or enemy special forces, infiltrate through the border quickly since they are trained and they move in the form of small groups whereas it takes time for refugees to infiltrate since they move in the form of large groups. We present the number of infiltrations caught/couldn't caught and probability of catching for each type of illegal infiltrations in Figures 4.5g-4.5h. As seen in these figures, the probabilities of catching enemy special force and terrorist type of infiltrations are low whereas the probability of catching refugee type of infiltrations is high. To increase the catching probability, we have to extend the infiltration time of illegal infiltrations. Therefore, precautions must be taken such as building physical obstacles at some parts of border to extend the infiltration time of illegal infiltrations.

4.2.4. Analysis of Relationships Between Performance Measures

When we analyzed the ROIIC performance measure in Section 4.2.3, we stated that there might be some relationships between DOC, FOC and ROIIC. We now exploit these relationships between these performance measures.

4.2.4.1. Relationship Between Degree of Controllability and Ratio of Illegal Infiltrations Caught

First, we construct a graph that displays the results of each performance measure at each zone. As seen in Figure 4.5, there is a high correlation between these two measures. Specifically, ROIIC increases as DOC increases.

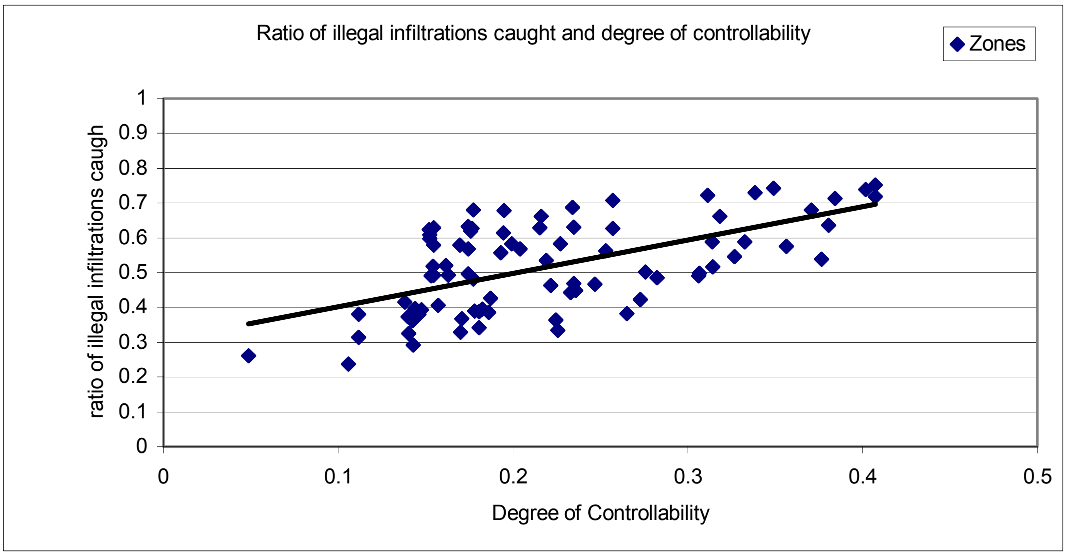


Figure 4.6. Correlation Between Ratio of Illegal Infiltrations Caught and Degree of Controllability

We also take additional simulation experiments to investigate the relationships between DOC and ROIIC by changing the capacity of security elements (patrols, ambushes, thermal camera, askarad). As will be explained in Section 4.2.4.2, there are interactions between FOC and ROIIC, and patrols are the main factor affecting FOC. To identify the relationship between DOC and ROIIC accurately without mixing up with the one between FOC and ROIIC, we don't increase the capacity of patrols, while changing the capacities of other security elements (ambushes, thermal camera, askarad). But, to observe the relationships at low levels of DOC, we decrease the capacity of patrols from the point that no security element except patrols exists in the system. The simulation results after changes are given in Table 4.3 (all these changes are called policies in the table). As seen in Figure 4.7, there is a relationship between DOC and ROIIC (ROIIC increases as the DOC increases). Figure 4.8 displays the relationship between DOC, ROIIC and cost for various capacities of security elements. Notice that the capacity increase is achieved by the multiples of the base capacity.

Table 4.3. Policies and results of performance measures

Policy no	Policies to obtain different amount of degree of controllability	Degree of Controllability	Ratio of Illegal Infiltrations Caught	Increase in the capacity of security elements
1	There is no security elements in the system	0	0	0
2	Patrols 720. Others not in the system*	0.0303	0.132	0
3	Patrols 360. Others not in the system*	0.0467	0.2504	0
4	Patrols 180. Others not in the system*	0.069	0.4382	0
5	Patrols 180. Others 3600*	0.1076	0.4578	0.2
6	Patrols 180. Others 2880*	0.1181	0.4721	0.25
7	Patrols 180. Others 1440*	0.1524	0.4888	0.5
8	Patrols 180. Others 720*	0.2199	0.5307	1
9	Patrols 180. Others 470*	0.272	0.5444	1.5
10	Patrols 180. Others 360*	0.3133	0.5621	2
11	Patrols 180. Others 270*	0.3598	0.5772	2.66
12	Patrols 180. Others 240*	0.4028	0.5915	3
13	Patrols 180. Others 180*	0.452	0.6019	4
14	Patrols 180. Others 144*	0.485	0.6233	5
15	Patrols 180. Others 120*	0.5155	0.6359	6
16	Patrols 180. Others 102*	0.5503	0.6519	7
17	Patrols 180. Others 90*	0.5788	0.6586	8
18	Patrols 180. Others 80*	0.6049	0.6778	9
19	Patrols 180. Others 72*	0.6228	0.6847	10
20	Patrols 180. Others 50*	0.6898	0.7151	14
21	Patrols 180. Others 40*	0.7282	0.7295	18
22	Patrols 180. Others 30*	0.7712	0.7834	24

(*) The policies are based on the interarrival times. "Others" indicate ambushes, thermal camera and askarad. Capacity of security elements increase as the interarrival time decreases. Since the patrols are the main factor that affects the FOC, we don't increase the capacity of patrols from the point of their typical interarrival time. Thus, we can observe the relationship between DOC and ROIIC more accurately without mixing up the one between FOC and ROIIC.

In general, increase in the capacity of security elements improves DOC. But the main purpose of increasing DOC is to increase ROIIC. However, Figure 4.8 displays that improvement in DOC and ROIIC are not symmetric that is they do not proportionally increase. Because some parts of border cannot be controlled with high-tech devices (askarad, thermal camera) due to terrain conditions. This means that by increasing quantity of high-tech devices, we do not necessarily prevent infiltrations along border. Thus, border security planners must avoid unconsciously increase in the quantity of high-tech devices. Because, their additional costs can not be justified. Once the appropriate quantity of high-tech devices is identified, duty places of ambushes must be planned for parts of borderline that cannot be controlled with high-tech devices to maximize ROIIC.

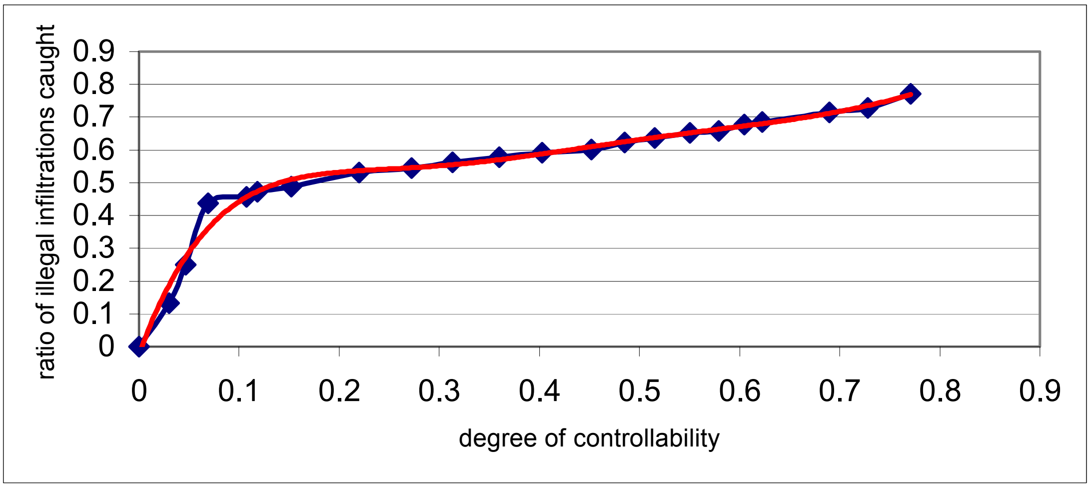


Figure 4.7. Relationship Between Degree of Controllability and Ratio of Illegal Infiltrations Caught

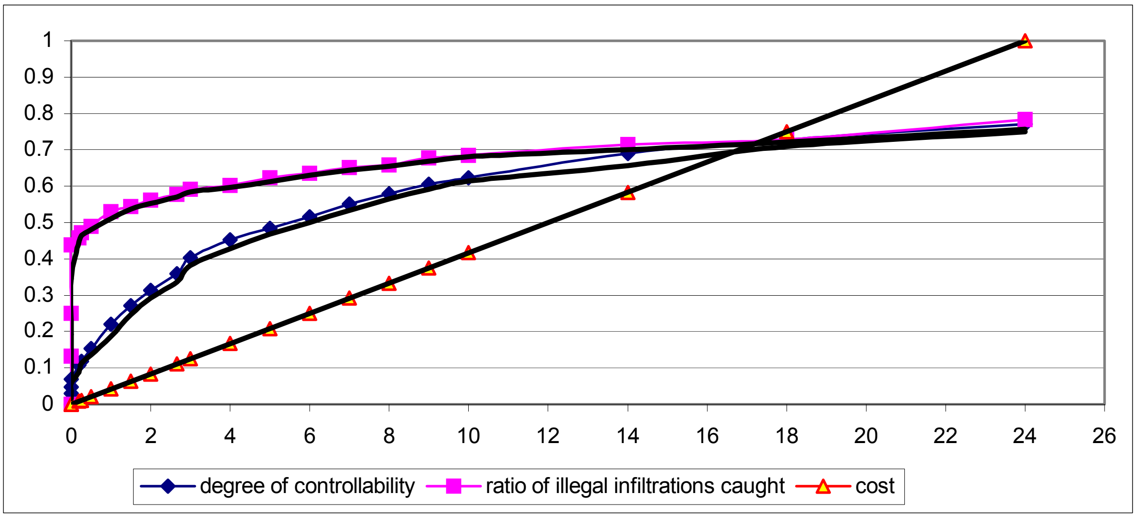


Figure 4.8. Relation between DOC, ROIIC, cost and capacity of security elements

4.2.4.2. Relationship Between Frequency of Controlling and Ratio of Illegal Infiltrations Caught

When analyzed FOC in Section 4.2.2, we stated that the main factor that affects the frequency of controlling was patrols. Thus, we conduct simulation experiments to explain the relationship between FOC and ROIIC by changing the capacity of patrols while keeping the capacity of other security elements constant. The simulation results after changes are given in Table 4.4 (all these changes are called policies in the table). As seen in Figure 4.9, there is a relationship between FOC and ROIIC (ROIIC increases as FOC increases). Figure 4.10 displays the relationship between DOC and ROIIC for various capacities of patrols. Notice that the capacity increase is achieved by the multiples of the base capacity of patrols.

In general, increase in the capacity of patrols improves FOC. But the main purpose of increasing FOC is to increase ROIIC. However, Figure 4.10 displays that improvement in FOC and ROIIC are not symmetric, that is they do not proportionally increase. This is due to low probability of catching illegal infiltrations such as terrorist or enemy special force. Because, they infiltrate through the border quickly since they are trained and they move in the form of small groups. This means that, by increasing capacity of patrols, we do not necessarily prevent infiltrations along border. Thus, border security planners must identify the appropriate quantity of patrols, and then precautions such as building of physical obstacles or increasing the mobility of patrols must be taken. Both precautions increase ROIIC. Because, physical obstacles extend the infiltration time of infiltrations and increasing the mobility of patrols increase FOC (recall that ROIIC increases as FOC increases).

Table 4.4. Policies and results of performance measures

Policy no	Policy	Frequency of Controlling	Ratio of Illegal Infiltrations Caught	Increase in the capacity of patrols
1	There is no security elements in the system	0	0	0
2	Patrols not in the system. Others 720*	179	0.2141	0
3	Patrols 720.Others 720*	651	0.3011	0.25
4	Patrols 360.Others 720*	1123	0.3851	0.5
5	Patrols 180.Others 720*	2052	0.5307	1
6	Patrols 135.Others 720*	2627	0.6049	1.33
7	Patrols 90.Others 720*	3651	0.7075	2
8	Patrols 60.Others 720*	5015	0.7948	3
9	Patrols 45.Others 720*	6173	0.8495	4
10	Patrols 30.Others 720*	8018	0.9075	5
11	Patrols 20.Others 720*	10080	0.95	9

(*)The policies are based on interarrival times. “Others” indicate ambushes, thermal camera and askarad. Capacity of patrols increases as the interarrival time decreases. Since main factor that affects the frequency of controlling is patrols, we change the capacity of patrols while keeping the capacity of other security elements constant.

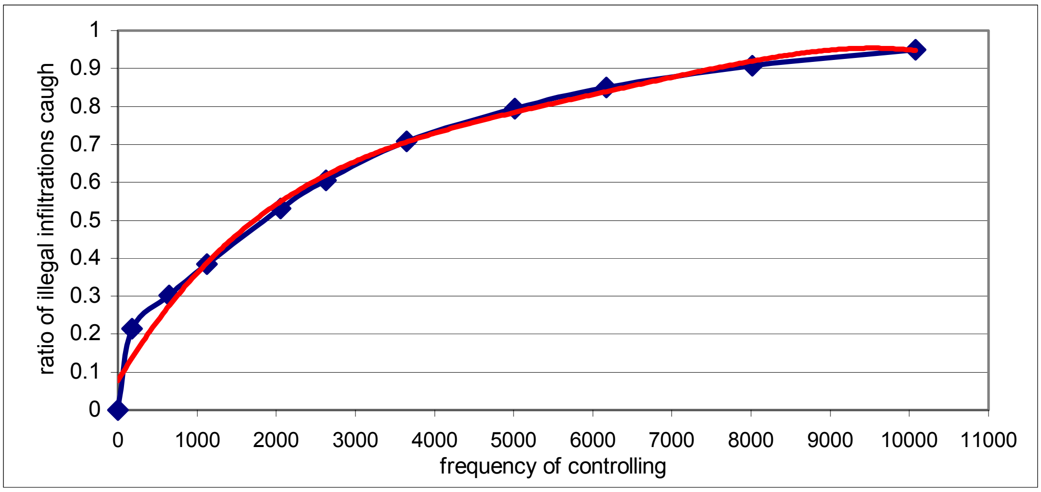


Figure 4.9. Relationship Between Frequency of Controlling and Ratio of Illegal Infiltrations Caught

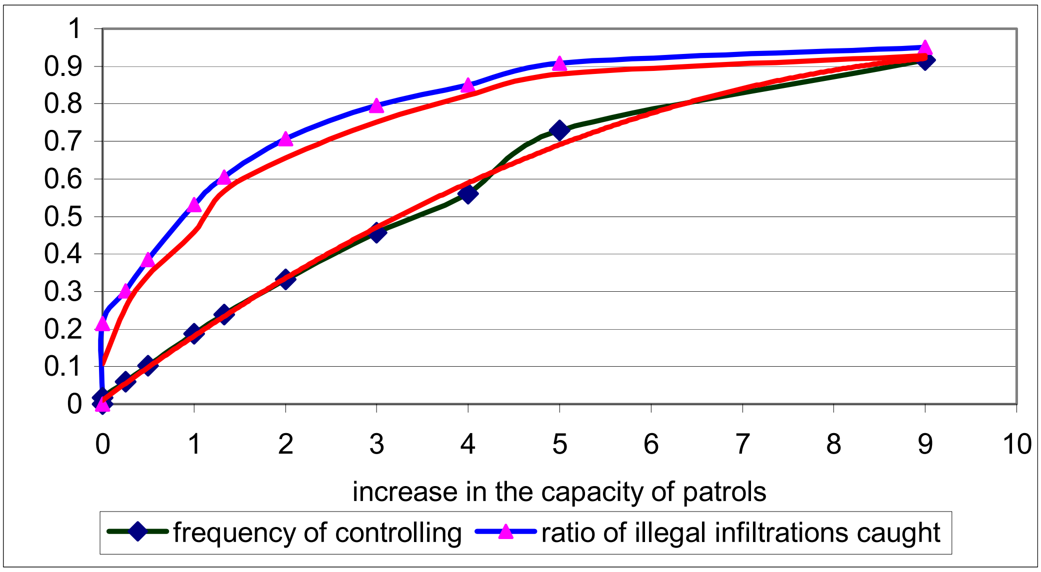


Figure 4.10. Relationship Between Performance Measures and Capacity of Patrols

4.3. Analysis of Effect of Each Security Element

One of the main research issues considered in our study is to evaluate the security elements, which constitute the border security system, according to their effects on the performance measures. It's important for any commander to know his troops capabilities. Commanders of border troops usually want to see the capabilities of security elements for protection of borders so that they can determine priorities for maintenance and training activities accordingly. We run a factorial design to assess the effect of each security element on each performance measure.

4.3.1. 2^4 Factorial Design

We consider each security element as a factor. Specifically, we have 4 factors (patrols, ambushes, thermal camera and askarad). As seen in Table 4.5, we set the high and low values of each factor according to whether the security element typically exists in the system or not.

Table 4.5.Factors Effecting Border Security System

FACTOR	FACTOR DESCRIPTION	-1	+1
A	PATROLS	NO PATROL IN THE SYSTEM	PATROLS ARE TYPICALLY IN THE SYSTEM
B	AMBUSHES	NO AMBUSH IN THE SYSTEM	AMBUSHES ARE TYPICALLY IN THE SYSTEM
C	THERMAL CAMERA	NO THERMAL CAMERA IN SYSTEM	THERMAL CAMERA IS TYPICALLY IN THE SYSTEM
D	ASKARAD	NO ASKARAD IN THE SYSTEM	ASKARAD IS TYPICALLY IN THE SYSTEM

We conduct our simulation experiments at 16 design points with 10 simulation replications. Results are presented in Appendix B (Tables B.1-B.3).

To have a sound statistical analysis, we have to check the homogeneity of variances and normality assumptions. Thus, we first applied Bartlett test (Montgomery 1992) and Levene test (Levene 1960). As presented in Table 4.6 and Table 4.7, homogeneity of variances is rejected for each performance measure.

Table 4.6. Levene Test Results

Performance measures	F	df1	df2	Significance value*	Test result
Ratio of Illegal Infiltrations Caught	2.720	15	144	**.001**	**reject**
Degree of Controllability	6.073	15	144	**.000**	**reject**
Frequency of Controlling	5.483	15	144	**.000**	**reject**

(*)A low significance value (generally less than 0.05) indicates that the variance differs significantly between groups.

Table 4.7 Bartlett Test Results

	PERFORMANCE MEASURES		
	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling
S_p^2	4.17E-05	1.13E-05	93.85977
q	43.8978852	71.08673	79.01167
c	1.04	1.04	1.04
χ_0^2	97.1916061	157.3888	174.9349
$\chi_{\alpha,a-1}^2$	25	25	25
test result	**Reject***	**Reject***	**Reject***

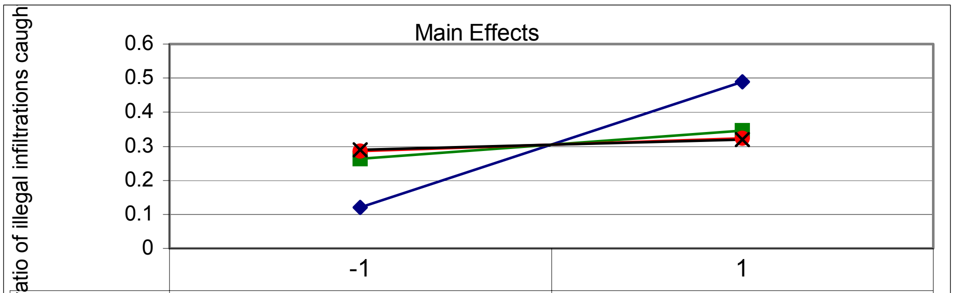
(*) we reject H_0, only when $\chi_0^2 > \chi_{\alpha,a-1}^2$

When we examine the results in detail (Appendix B, Tables B.1-B.3), we observe that variance of one of the design points (when there is no security element in the system) for each performance measure is zero. Since variance stabilization techniques cannot help due to zero variance data points, we use the results of factorial design as suggestive rather than conclusive. These diagrams for each performance measure are presented in Figure 4.11.

By considering these results, we conclude that the most effective factor for ROIIC is patrols (see Figure 4.11a). Other security elements also improve ROIIC, but not as much as patrols. In terms of DOC each security element improves DOC (Figure 4.11b). As seen in Figure 4.11c, patrols have positive effect for FOC whereas the others (ambush, thermal camera and askarad) have negative effects. Because, these security elements improve DOC. As discussed in detail in Section 4.2.2, FOC is less for the zones that DOC is at high level.

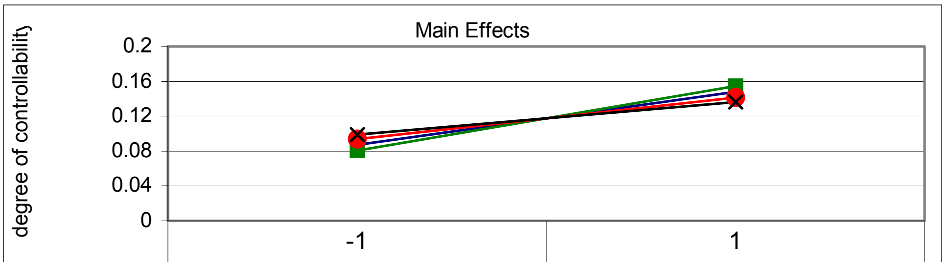
4.3.2. Paired-T Approach

We also apply the paired-T comparison to see if each security element has statistically impact on the performance measures or not. We use the data given in Appendix B (Tables B.1-B.3). The paired-T results are presented in Tables 4.8-4.10 for each performance measure. In these tables, “A” refers to the results of design point that all factors (security elements) are with their low value (security elements are not in the system). “All” refers to the results of design point that all factors are with their high value (all security elements are in the system). “PAT, AMB, TER, ASK” represents patrols, ambushes, thermal camera and askarad. “Pat-A” is the comparison of when only patrols are in the system and no security element in the system. “All-Pat” is the comparison of security elements are in the system and all security elements except patrols are in the system. All these results indicate that, with their existence in the system, each security element has significant effect on each performance measure.



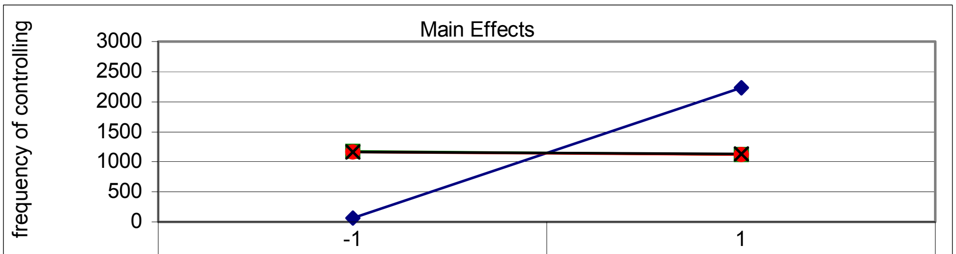
	-1	1
factor a	0.1199025	0.4896465
factor b	0.26312975	0.34641925
factor c	0.285651375	0.323897625
factor d	0.289831625	0.319717375

a) Main Effect Diagram (Ratio of illegal infiltrations Caught)



	-1	1
factor a	0.0869655	0.148215125
factor b	0.08080625	0.154374375
factor c	0.094042875	0.14113775
factor d	0.098834	0.136346625

b) Main Effect Diagram (Degree of Controllability)



	-1	1
factor a	64.45863125	2227.0885
factor b	1172.9	1118.56525
factor c	1166.720071	1124.82706
factor d	1158.443083	1133.104049

c) Main Effect Diagram (Frequency of Controlling)

Figure 4.11 Main effect diagrams of each performance measure

Table 4.8. Paired Samples Test for Ratio of Illegal Infiltrations Caught Performance Measure

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	**PAT - A**	.43813	7.018E-03	2.219E-03	.4331	.4431	197.394	9	**.000**
Pair 2	**AMB - A**	.13812	3.70E-03	1.172E-03	.1354	.1407	117.774	9	**.000**
Pair 3	**TER - A**	7.395E-02	5.330E-03	1.685E-03	7.0139E-02	7.776E-02	43.871	9	**.000**
Pair 4	**ASK - A**	6.019E-02	7.09E-03	2.245E-03	5.511E-02	6.527E-02	26.812	9	**.000**
Pair 5	**ALL - PAT**	.3180	1.013E-02	3.203E-03	.3108	.3253	99.282	9	**.000**
Pair 6	**ALL - AMB**	4.11E-02	6.73E-03	2.12E-03	3.635E-02	4.59E-02	19.333	9	**.000**
Pair 7	**ALL - TER**	1.79E-02	1.062E-02	3.361E-03	1.033E-02	2.55E-02	5.337	9	**.000**
Pair 8	**ALL - ASK**	1.22E-02	8.967E-03	2.835E-03	5.86E-03	1.869E-02	4.332	9	**.002**

Table 4.9. Paired Samples Test for Degree of Controllability Performance Measure

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	**PAT - A**	6.901E-02	1.525E-04	4.82E-05	6.890E-02	6.91E-02	1430.907	9	**.000**
Pair 2	**AMB - A**	8.291E-02	1.246E-03	3.94E-04	8.202E-02	8.3808E-02	210.392	9	**.000**
Pair 3	**TER - A**	5.625E-02	3.162E-03	1.00E-03	5.399E-02	5.852E-02	56.255	9	**.000**
Pair 4	**ASK - A**	4.414E-02	4.438E-03	1.40E-03	4.097E-02	4.732E-02	31.453	9	**.000**
Pair 5	**ALL - PAT**	5.339E-02	6.837E-03	2.162E-03	4.85E-02	5.828E-02	24.694	9	**.000**
Pair 6	**ALL - AMB**	6.284E-02	6.226E-03	1.969E-03	5.83E-02	6.729E-02	31.914	9	**.000**
Pair 7	**ALL - TER**	3.98E-02	5.209E-03	1.64E-03	3.607E-02	4.352E-02	24.157	9	**.000**
Pair 8	**ALL - ASK**	3.137E-02	4.07E-03	1.28E-03	2.84E-02	3.428E-02	24.329	9	**.000**

Table 4.10. Paired Samples Test for Frequency of Controlling Performance Measure

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	**PAT - A**	2412.44	12.847	4.062	2403.25	2421.636	593.797	9	**.000**
Pair 2	**AMB - A**	65.0	1.4380	.4547	63.977	66.034	142.950	9	**.000**
Pair 3	**TER - A**	37.45	1.906	.6029	36.0920	38.8198	62.126	9	**.000**
Pair 4	**ASK - A**	33.02	4.1859	1.3237	30.028	36.0158	24.946	9	**.000**
Pair 5	**ALL - PAT**	1923.07	21.888	6.9218	1907.418	1938.7357	277.826	9	**.000**
Pair 6	**ALL - AMB**	-167.411	21.166	6.693	-182.553	-152.270	-25.012	9	**.000**
Pair 7	**ALL - TER1**	-115.70	24.521	7.754	-133.241	-98.158	-14.921	9	**.000**
Pair 8	**ALL - ASK1**	-71.978	18.756	5.931	-85.396	-58.560	-12.135	9	**.000**

CHAPTER 5

Design and Analysis of Experiments

In the previous chapter, we analyzed the system behavior by examining the relationships between the security elements and the performance measures and relationships between the performance measures. We also investigated effects of each security element on each performance measure. Since the security elements have significant affects, we further examine them for various policies in this chapter.

The degree of use of security elements, stationary or mobile use of security elements, time period that patrols spend on border control and type of patrols (motorized or on-foot) are such policies about how security elements are used for protection of borders. In this chapter, we study for how and how much do such policies affect the system performances and find out the possible ways of improving performance measures.

5.1. 2^5 Factorial Design

In Chapter 4.3.1, we have performed 2^4 factorial design to assess the effect of each security element (patrols, ambushes, thermal camera and askarad) on the performance measures. In this chapter, we investigate the effects of different policies on each performance measure. The policies are (1) the degree of use of high-tech devices, (2) the degree of use of night-vision tools, (3) stationary or mobile characteristics of duty, (4) the degree of use of motorized patrols, (5) duty time of patrols. We consider these policies as factors that affect the system performances, such as ratio-of-illegal-infiltrations-caught, degree-of-controllability, frequency-of-controlling.

We determine these factors and their levels according to Border Services Instruction (KKY 118-1) and by consulting military experts. All factors are controllable. It is recommended in Border Services Instruction not to use high-tech devices frequently. Because, it is desired to extend the lifetime of these devices. Moreover, failure of these devices is an undesired situation for commanders. Thus, they may prefer to use these devices seldom. On the other hand, operational activities for protection of borders need these devices. Above statements are valid for night-vision tools and motorized patrols. Therefore, we set low and high values of factors *a*, *b* and *d* according to how frequent these devices are used. The levels of factors indicate the probability of use of the high-tech devices or night-vision tools for duty of that day. The commander determines stationary or mobile characteristics of duty. This varies according to number of critical zones or terrain conditions. The levels of the factor indicate what percent the duty will be mobile. The maximum time that patrols spent on border control is determined as 4 hours in Border Services Instruction. But most of the troops apply 3-hour policy. The factors and their levels are presented in Table 5.1.

Table 5.1. Factors and levels of 2^5 factorial design

FACTOR	FACTOR DESCRIPTION	-1	+1
A	The degree of use of high-tech devices	40%	95%
B	The degree of use of night-vision tools	25%	75%
C	Determination of stationary or mobile characteristics of duty	30%	70%
D	The degree of use of motorized patrols	15%	70%
E	Duty time of patrols	3 hours	4hours

We implement 2^5 factorial design study, which consists of 32 design points. We investigate the main and interaction effects of factors on each system response. We take 10 simulation runs of each design point, so that the randomization is satisfied to make factorial design. Results of 2^5 factorial design for each performance measure are presented in Appendix C (Table C.3-C.5). To find out the significant factors and their interactions, we implement analysis of variance (ANOVA).

5.2. Implementation of ANOVA

To implement analysis of variance, two main ANOVA assumptions (homogeneity of variances and normality) must be satisfied. Because any violation of ANOVA assumptions may cause serious problems in the final analysis.

Homogeneity of Variances

We test the following hypothesis:

$H_0 : \sigma_1^2 = \sigma_2^2 = ... = \sigma_a^2$

H_1: above not true for at least one σ_i^2

We apply Bartlett's (Montgomery 1992) and Levene's (Levene 1960) tests. The results are presented in Tables 5.2-5.3.

Table 5.2. Bartlett test results for 2^5 factorial design

	PERFORMANCE MEASURES		
	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling
S_p^2	2.05E-06	2.78E-07	7.463576
q	-364.848	-496.514	-462.141
c	1.02	1.02	1.02
χ_0^2	-823.626	-1120.86	-1043.26
$\chi_{\alpha,a-1}^2$	45	45	45
test result	**Do not reject**	**Do not reject**	**Do not reject**

Where, $\chi_0^2 = 2.3026\frac{q}{c}$ $\quad q = (N-a)\log_{10} S_p^2 - \sum_{i=1}^{a}(n_i - 1)\log_{10} S_i^2$

$$c = 1 + \frac{1}{3(a-1)}\left(\sum_{i=1}^{a}(n_i - 1)^{-1} - (N-a)^{-1}\right)$$

$$S_p^2 = \frac{\sum_{i=1}^{a}(n_i - 1)S_i^2}{N-a}$$

we reject H_0, only when $\chi_0^2 > \chi_{\alpha,a-1}^2$

Table 5.3. Levene test results for 2^5 factorial design

Performance measures	F	df1	df2	Significance value*	Test results
Ratio of illegal infiltrations caught	.932	31	288	**.575**	**Do not reject**
Degree of controllability	.794	31	288	**.776**	**Do not reject**
Frequency of controlling	1.648	31	288	**.020**	**reject**

(*)The Levene statistic tests the hypothesis of equality of variance of the dependent variable for groups. A low significance value (generally less than 0.05) indicates that the variance differs significantly between groups.

Bartlett test results in Table 5.2 indicate that homogeneity of variances is satisfied for each performance measure. But, Levene test results in Table 5.3 indicate that homogeneity of variances is not satisfied for FOC. To be on the safe side, we decided to take the suggestion of Levene test (i.e., we accept the results of Levene test). We further analyze the results of 2^5 factorial design for FOC presented in Appendix C (Table C.5). These results indicate that frequency-of-controlling is highly affected by factor *d* (degree of use of motorized patrols). We compare the results of design points when factor *d* is with its high value and the results of design points when factor *d* is with its low value by using t test. The test result is presented in Table 5.4.

Table 5.4. t-test for FOC

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
								Lower	Upper
X Equal variances assumed	3.852	.059	17.22	30	**.000**	733.803	42.5915	616.676	850.929
Equal variances not assumed			17.22	25.86	**.000**	733.803	42.5915	615.40	852.201

As seen in Table 5.4, there is statistically significant difference between two groups of results. This means that the motorized patrols make big differences in the data set. This in turn breaks the common variance assumption. Thus we decided to implement two 2^4 factorial designs instead of 2^5 for the FOC measure by isolating this factor. When we apply Bartlett and Levene for 4 factors, we see that homogeneity of variances is satisfied (see the results in Table 5.5-5.6). Scatter plots given in Appendix D (Figure D.1a-D.1d) also confirm the common variance assumption.

Table 5.5. Bartlett Test Results For 2^4 Factorial Design

	Frequency of Controlling	
	Motorized patrol with high level	Motorized patrol with low level
S_p^2	488.3762	227.5717
q	3.95793	9.098046
c	1.04	1.04
χ_0^2	8.763009	20.14342
$\chi^2_{\alpha,a-1}$	25	25
test result	**Do not reject**	**Do not reject**

Table 5.6. Levene Test Results For 2^4 Factorial Design

	F	df1	df2	Significance value
Motorized patrol with high level	.858	15	144	**.611**
Motorized patrol with low level	1.228	15	144	**.257**

Normality Assumptions

A check of the normality assumption can be made by plotting a histogram of residuals. The residuals for the ith treatment are found by subtracting the treatment average from each observation in that treatment. Residuals are presented in Appendix D (Table D.1). If the normality assumption is satisfied, histogram of residuals should look like a sample from a normal distribution centered at zero. The histogram compared with normal is presented in Figure 5.1 for the ROIIC performance measure. In Appendix D (Figure D.2a-D.2c) histograms are presented for other two measures (FOC and DOC). As seen in these figures, histogram of residuals look like a sample from a normal distribution centered at zero. It shows us the normality assumption for each performance measure is satisfied.

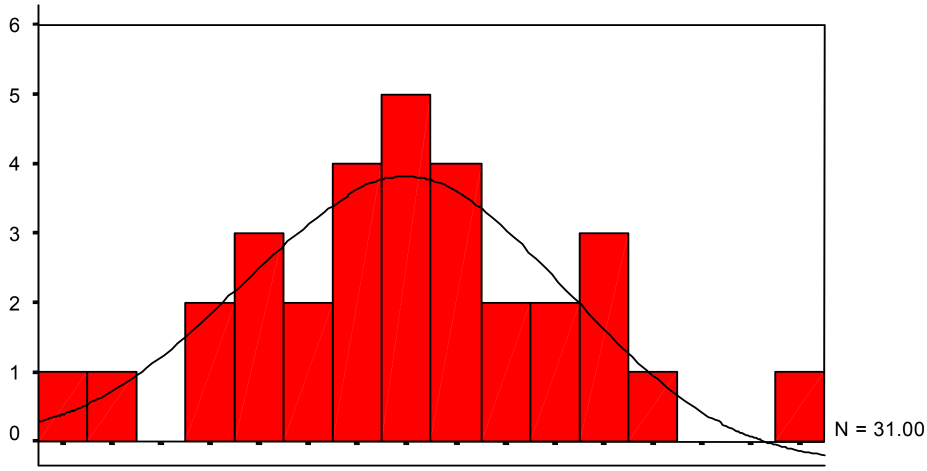


Figure 5.1. Histogram of residuals compared with normal for ratio of illegal infiltrations caught

Another useful procedure is to construct a normal probability plot of residuals. If the distribution is normal, this plot will resemble a straight line. The normal probability plot of residuals for ROIIC is presented in Figure 5.2. In Appendix D (Figures D.3a-D.3c), normal probability plots are presented for FOC and DOC. As seen in these figures, plots of residuals resemble a straight line. It shows that the normality assumption is satisfied for each performance measure. Scatter plot of residuals are also presented in Appendix D (Figures D.4a-D.4d). As seen in these figures, residuals are structureless that is; normality assumption is satisfied for each performance measure.

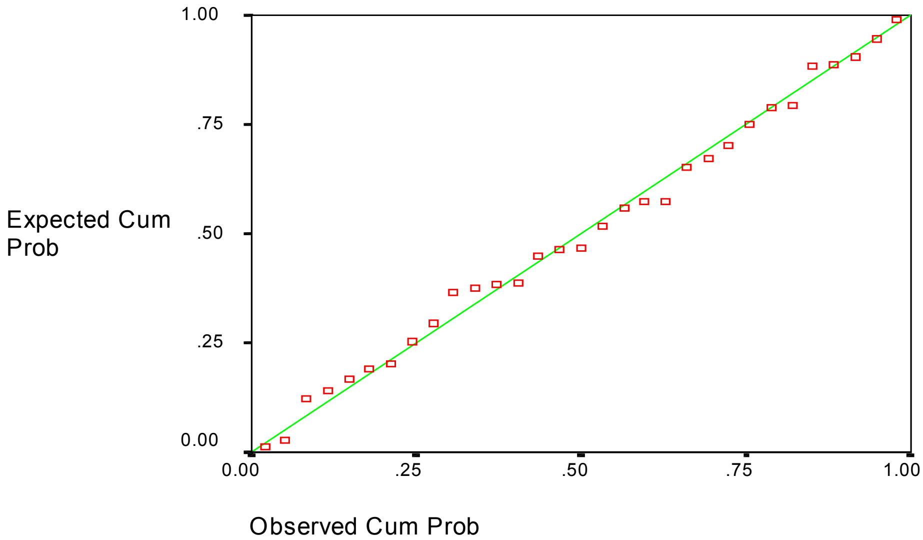


Figure 5.2. Normal P-P of residuals for ratio of illegal infiltrations caught

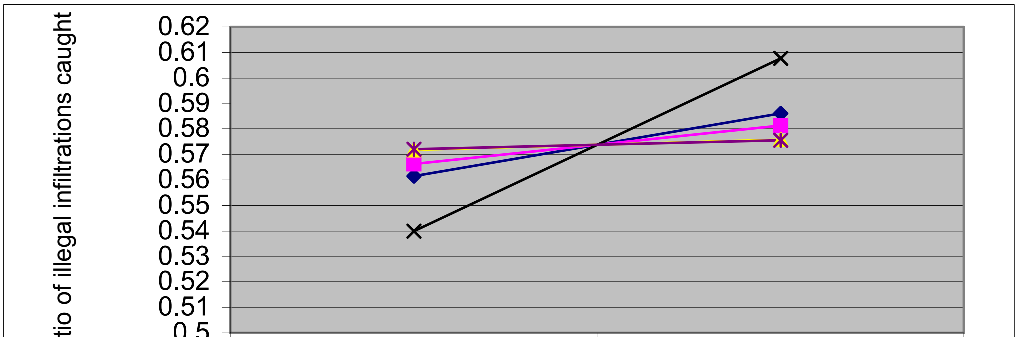
After satisfying analysis of variance assumptions, we calculate the main and interaction effects of the factors for each performance measure. The ANOVA test is implemented by using SPSS statistical package program and the results are presented in Appendix C (Table C.6-C.10) for each performance measure. Normal probability plot of main and interaction effects are presented in Appendix C (Table C.11 and Figures C.1a-C.1d) to validate the ANOVA results (as seen in these figures, all of the insignificant effects of ANOVA results lie along the zero line, whereas the significant effects are far from line).

5.3. Interpretation of ANOVA Results of the Performance Measures

In this section, we interpret main and interaction effects of factors for each performance measure by analyzing the ANOVA results. Recall that our performance measures are ratio-of-illegal-infiltrations-caught (ROIIC), degree-of-controllability (DOC) and frequency-of-controlling (FOC).

5.3.1. Interpretation of Main Effects and Interactions of Ratio of Illegal Infiltrations Caught Performance Measure.

The SPSS output of ROIIC statistics is given in Appendix D (Table C.6). It is clear that each factor is significant. We present the main effect diagram of factors for ROIIC in Figure 5.3. As seen in this figure, factor *d* (degree of use of motorized patrols) has the greatest effect on ROIIC. This is due to increase in the mobility of patrols. When the motorized type of patrols increase, frequency of controlling the zones increases. Recall from Chapter 4 (Section 4.2.4.2) that the ROIIC improves as FOC increases. FOC increases 38% when degree of use of motorized patrols is at its high level as seen in Figure 5.7. This improvement in FOC increases ROIIC 13% (Figure 5.3). When factor *a* (degree of use of high-tech devices) is at high level, DOC increases 28% (Figure 5.5). Recall from Chapter 4 (Section 4.2.4.1) that ROIIC increases as DOC increases but not proportionally. The improvement in DOC increases ROIIC 5% (Figure 5.3).



	-1	1
factor a	0.561457318	0.586154383
factor b	0.56637895	0.581232751
factor c	0.571692111	0.57591959
factor d	0.539943338	0.607668363
factor e	0.571994277	0.575617424

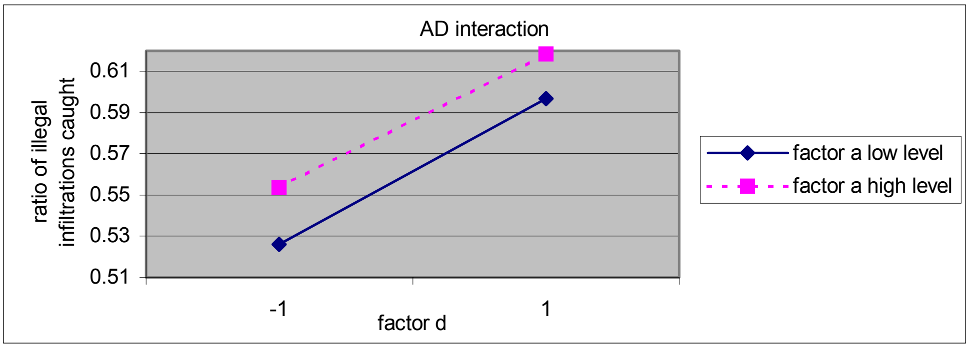
Figure 5.3. Main effect diagram of factors for ratio of illegal infiltrations caught

The graphs in Figure 5.4 are very useful in interpreting significant interactions. However, they should not be utilized as the sole technique of data analysis because their interpretation is subjective and their appearance is often misleading (Montgomery 1992). Therefore, in addition to these graphs, we construct Tables 5.7-5.9 for each performance measure.

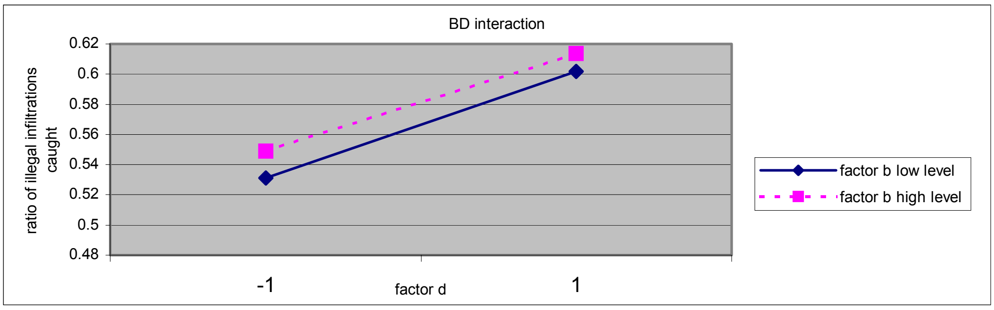
There are four significant interactions on ROIIC. These are between factors *a-d*, *b-d, e-d* and *a-b-d-e*. Notice that interactions are between factors (*a, b and e*) that have positive effect on DOC and factor (*d*) that has positive effect on FOC (explanation is given in Sections 5.3.2 and 5.3.3. The interactions between factors are presented in Figure 5.4a-5.4d. In these figures, the two lines are parallel to each other that indicate a lack of interaction. Thus, we explain interactions by using results in Table 5.7. There is an interaction between factors *a* and *d* since the effect of factor *d* on ROIIC depends on the level chosen for factor *a*. When the degree of use of high-tech devices is high, longer time the zones will be under control and this will decrease the control of zones by patrols (as explained in Chapter 4.2.2). When the degree of use of high-tech devices is low, less time the zones will be under control and this will increase the control of zones by patrols. Thus, effect of factor *d* on ROIIC will be less when factor *a* is with its high value and effect of factor *d* on ROIIC will be more when factor *a* is with its low value. Interactions *b-d* and *e-d* can be explained by same reasoning since factors *b* and *e* are like factor a (factors that increase DOC) and the second factor in the interactions is factor *d* same as in interaction *a-d.* The last interaction, *abde*, consists of factors that are in the two-interactions. As seen in Table 5.7 (four interaction), when the three factors (*a, b, e*) are with their high levels, the effect of factor *d* on ROIIC is less and when the three factors (*a, b, e*) are with their low levels, the effect of factor *d* on ROIIC is more.

Table 5.7. Interactions between factors for ROIIC

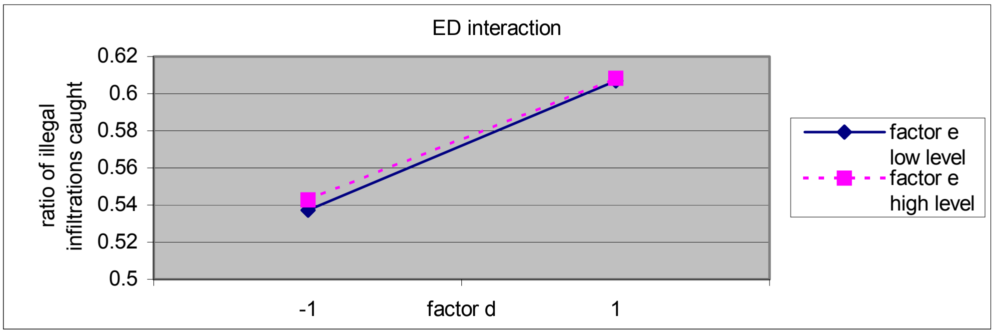
<table>
<tr><td>Interactions</td><td colspan="5">Ratio of Illegal Infiltrations Caught</td></tr>
<tr><td rowspan="5">AD</td><td colspan="2" rowspan="2"></td><td colspan="3">D</td></tr>
<tr><td>high</td><td>low</td><td>difference</td></tr>
<tr><td rowspan="3">A</td><td>high</td><td>0.6185</td><td>0.5537</td><td>0.0648</td></tr>
<tr><td>low</td><td>0.5967</td><td>0.5261</td><td>0.0706</td></tr>
<tr><td>difference</td><td>0.0218</td><td>0.0276</td><td></td></tr>
<tr><td rowspan="5">BD</td><td colspan="2" rowspan="2"></td><td colspan="3">D</td></tr>
<tr><td>high</td><td>low</td><td>difference</td></tr>
<tr><td rowspan="3">B</td><td>high</td><td>0.6137</td><td>0.5487</td><td>0.065</td></tr>
<tr><td>low</td><td>0.6016</td><td>0.0705</td><td>0.0705</td></tr>
<tr><td>difference</td><td>0.0121</td><td>0.0176</td><td></td></tr>
<tr><td rowspan="5">ED</td><td colspan="2" rowspan="2"></td><td colspan="3">D</td></tr>
<tr><td>high</td><td>low</td><td>difference</td></tr>
<tr><td rowspan="3">E</td><td>high</td><td>0.6081</td><td>0.5427</td><td>0.0654</td></tr>
<tr><td>low</td><td>0.6068</td><td>0.5371</td><td>0.0697</td></tr>
<tr><td>difference</td><td>0.0013</td><td>0.0056</td><td></td></tr>
<tr><td rowspan="5">ABDE</td><td colspan="2" rowspan="2"></td><td colspan="3">D</td></tr>
<tr><td>high</td><td>low</td><td>difference</td></tr>
<tr><td rowspan="3">ABE</td><td>high</td><td>0.6260</td><td>0.5876</td><td>0.0384</td></tr>
<tr><td>low</td><td>0.5634</td><td>0.5149</td><td>0.048</td></tr>
<tr><td>difference</td><td>0.0625</td><td>0.0726</td><td></td></tr>
</table>



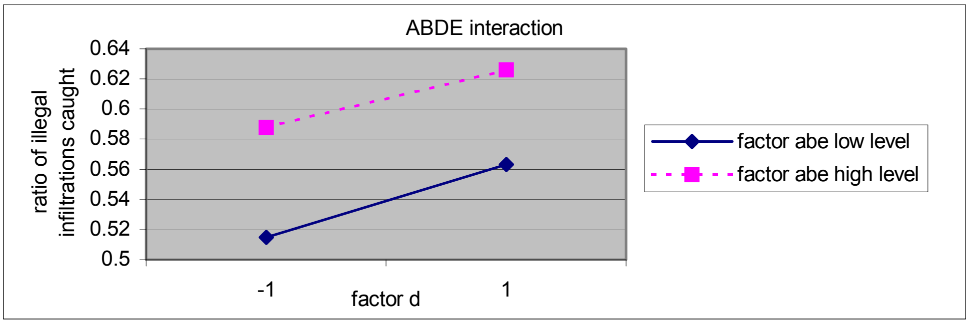
a) Interaction between factor *a* and *d*



b) Interaction between factor *b* and *d*



c) Interaction between factor *e* and *d*

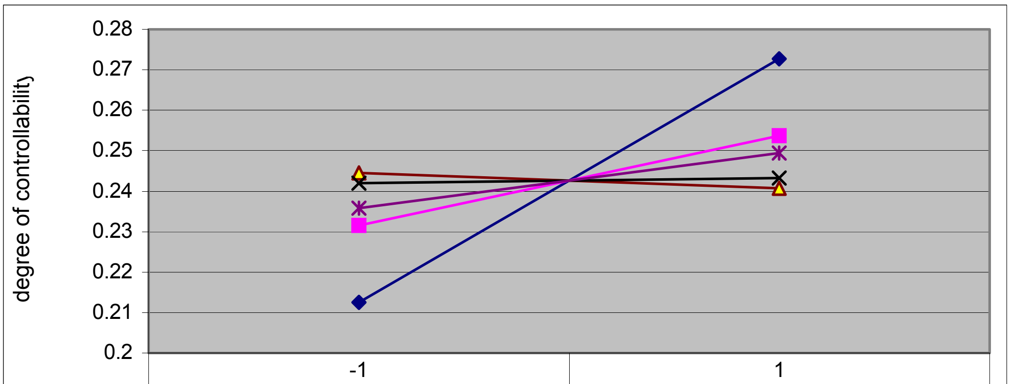


d) Interaction between factor *a,b,e* and *d*

Figure 5.4. Interactions between factors

5.3.2. Interpretation of Main Effects and Interactions of Degree of Controllability Performance Measure

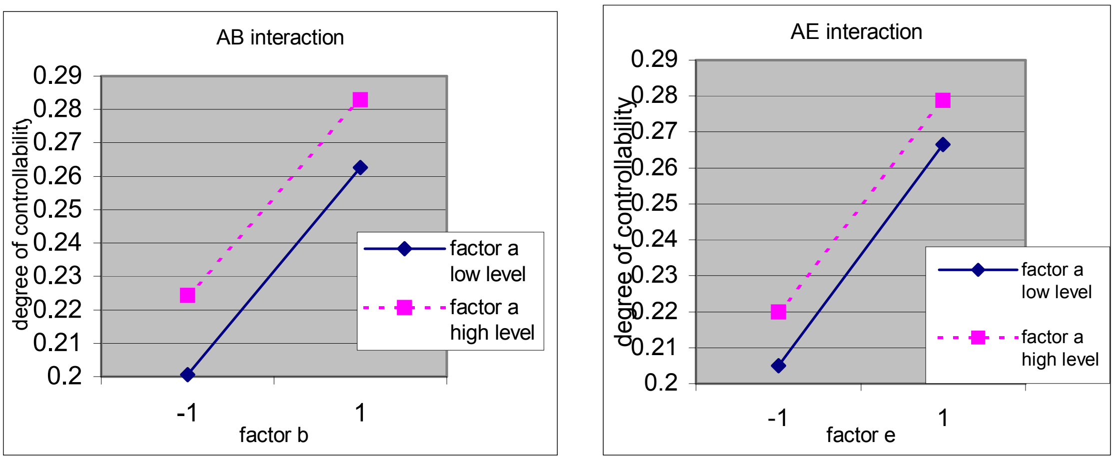
The SPSS output of DOC statistics is given in Appendix D (Table C.7). The results indicate that each factor is significant. As seen in Figure 5.5, factor *a* (degree of use of high-tech devices) has the greatest effect on DOC. This is due to usage of high-tech devices more frequently. When degree of use of high-tech devices is high, longer time the zones are under control. Then, DOC increases 28% when degree of use of high-tech devices is at high level as seen in Figure 5.5.



	-1	1
factor a	0.212489856	0.272734808
factor b	0.231557816	0.253666849
factor c	0.244487654	0.24073701
factor d	0.241908541	0.243316124
factor e	0.235839083	0.249385581

Figure 5.5. Main effect diagram of factors for degree of controllability

There are two significant interactions on DOC. These are between factors *a-b* and *a-e*. Notice that interactions are between factors that have all positive effect on DOC. The *interactions* between factors are presented in Figure 5.6a-5.6b and Table 5.8. There is an interaction between *a* and *b* since the effect of factor *b* on DOC depends on the level chosen for factor *a*. When the degree of use of high-tech devices is high, longer time the zones will be under control and this will increase the probability of taking the same zones under control by ambushes and patrols. Thus, effect of factor *b* on DOC will be less when factor *a* is with its high value and effect of factor *b* on DOC will be more when factor *a* is with its low value. Interaction *a-e* can be explained by same reasoning since factor *e* is like factor *b* (factors that increase DOC) and the second factor in the interaction is factor *a* same as in interaction *a-b*.



a) Interaction between factor *a* and *b* b) Interaction between factor *a* and *e*

Figure 5.6. Interactions between factors

Table 5.8. Interactions between factors for degree of controllability

Interaction	Degree Of Controllability				
AB			B		
			high	low	difference
	A	high	0.2829	0.2625	0.0204
		low	0.2244	0.2005	0.0239
		difference	0.0585	0.062	
AE			E		
			high	low	difference
	A	high	0.2788	0.2199	0.0589
		low	0.2666	0.2050	0.0616
		difference	0.0122	0.0149	

5.3.3. Interpretation of Main Effects and Interactions of Frequency of Controlling Performance Measure

The SPSS output of FOC statistics is given in Appendix D (Table C.8-C10). The results indicate that each factor is significant. As seen in Figure 5.3, factor *d* (degree of use of motorized patrols) has the greatest effect on FOC. This is due to increase in the mobility of patrols. When the degree of use of motorized patrols is high, frequency of controlling the zones increases. FOC increases 38% when degree of use of motorized patrols is at high level as seen in Figure 5.5.

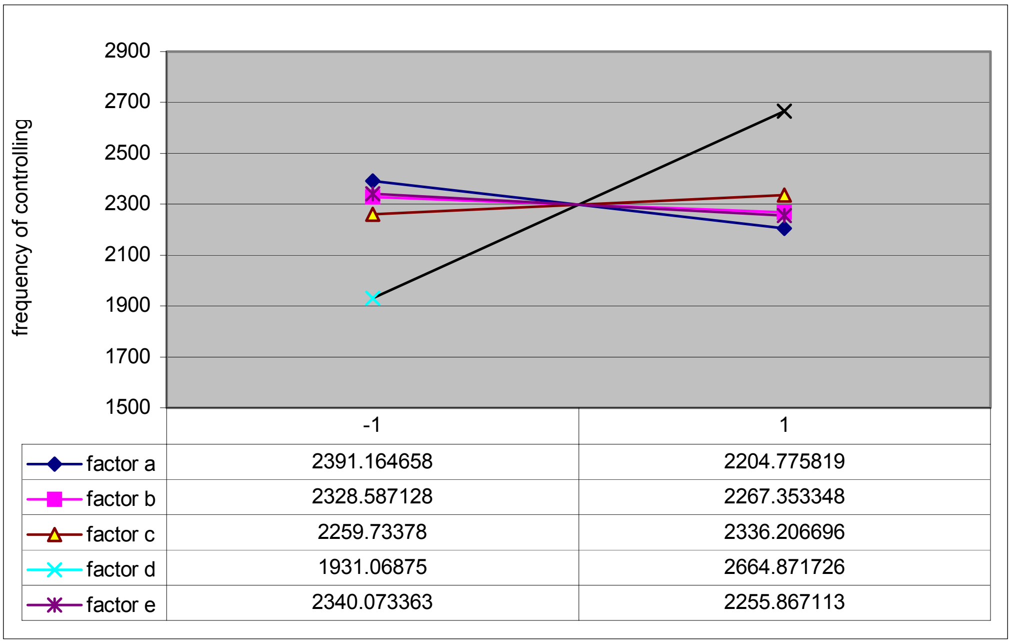
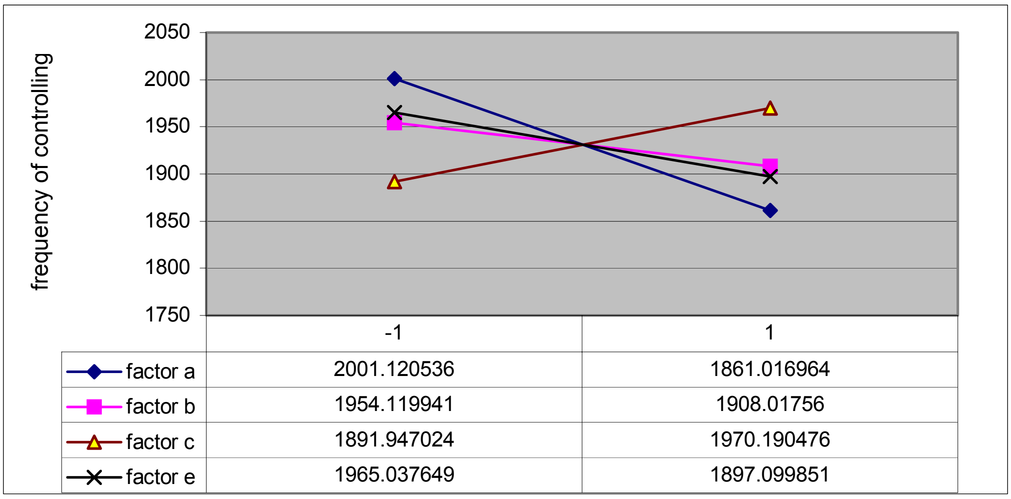
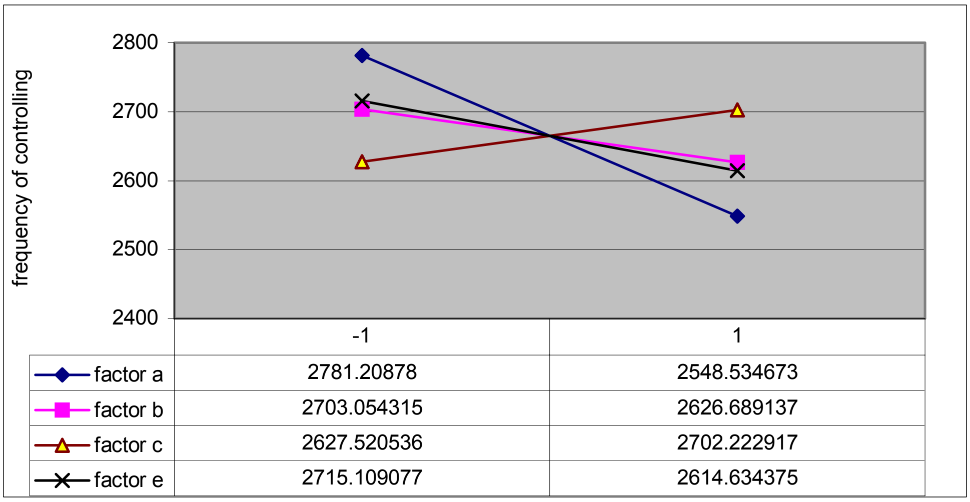


Figure 5.7. Main effect diagram of factors for frequency of controlling

We divided 2^5 factorial design into two 2^4 factorial designs as we discussed in the homogeneity of variances section (Section 5.2). As seen in Figures 5.7a-5.7b both 2^4 factorial design main effect graphs are similar. Factor *c* (stationary or mobile characteristics of duty) has the greatest effect on FOC. This is due to increase in the



a) Main effect diagram of factors for frequency of controlling
(factor *d* is with its low value)



b) Main effect diagram of factors for frequency of controlling
(factor *d* is with its high value)

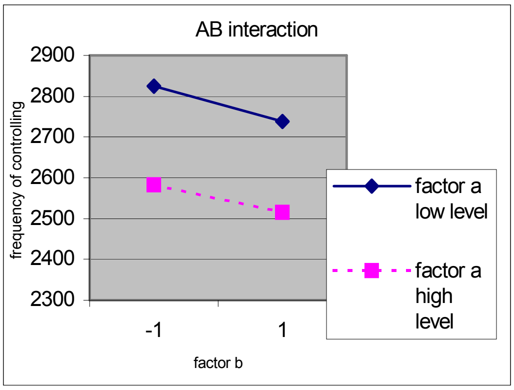
Figure 5.8. Main effect diagram of factors for frequency of controlling

mobile duties. When mobile duties increase, frequency of controlling the zones increases. FOC increases 4% when factor *c* is with its high level. Factors *a, b* and *e* have negative effect on FOC. This is due to increase in the DOC. These factors improve DOC, since longer time the zones will be under control when they are with their high levels. Recall from Chapter 4.2.2 that FOC is less for the zones that DOC is at high level.

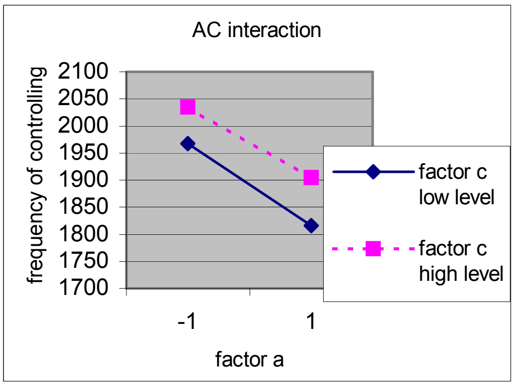
There are four significant interactions on FOC. These are between factors *a-c, a-b, b-c* and *b-e*. The interactions between factors are presented in Figure 5.9a-5.9d and Table 5.9. Interactions between factors *a-b* and *b-e* are between factors that have positive effect on DOC. These interactions can be interpreted as the ones in Section 5.3.2. Interactions between factors *a-c* and *b-c* are between factors (*a, b*) that have positive effect on DOC and factor (*c*) that has positive effect on FOC. These interactions can be interpreted as the ones in Section 5.3.1.

Table 5.9. Interactions between factors for frequency of controlling

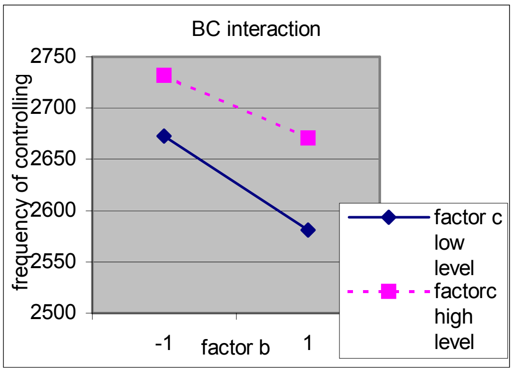
Interactions	Frequency of controlling				
AB			B		
			high	low	difference
	A	high	2515	2582	-67
		low	2738	2824	-86
		difference	-223	-242	
BC			B		
			high	low	difference
	C	high	2671	2732	-61
		low	2581	2673	-92
		difference	90	59	
BE			B		
			high	low	difference
	E	high	2571	2657	-86
		low	2681	2748	-67
		difference	-110	-91	
AC			A		
			high	low	difference
	C	high	1905	2034	-129
		low	1816	1967	-151
		difference	89	67	



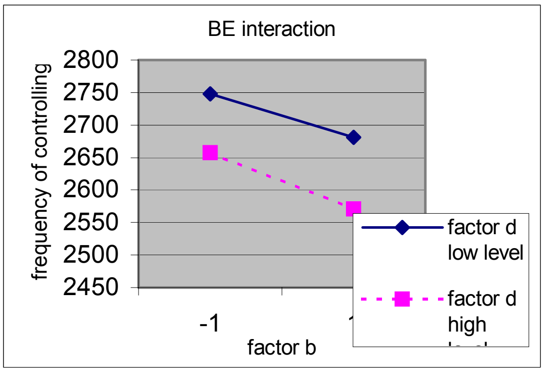
a) Interaction between factors *a* and *c*



b) Interaction between factors a and *b*



c) Interaction between factors *b* and *c*



d) Interaction between factors *b* and *e*

Figure 5.8 Interactions between factors

All these results are summarized in Table 5.10. Specifically, the magnitude and the direction of the factor effects on each performance are given in this table. Note that the effects of the factors are measured when we change the level of the factors from its low level to high level.

Table 5.10. Results of the factors affecting the performance measures

Performance measures	**Significant factors**	**Improvement**
Degree of controllability	The degree of use of high-tech devices	28%
	The degree of use of night-vision tools	10%
	Determination of stationary or mobile characteristics of duty	-1%
	The degree of use of motorized patrols	1%
	Duty time of patrols	6%
Frequency of controlling	The degree of use of high-tech devices	-8%
	The degree of use of night-vision tools	-3%
	Determination of stationary or mobile characteristics of duty	4%
	The degree of use of motorized patrols	38%
	Duty time of patrols	-4%
Ratio of illegal infiltrations caught	The degree of use of high-tech devices	5%
	The degree of use of night-vision tools	3%
	Determination of stationary or mobile characteristics of duty	1%
	The degree of use of motorized patrols	13%
	Duty time of patrols	1%

In concluding this chapter, we observe that factor *d* (degree of use of motorized patrols) has the greatest effect on ROIIC. FOC increases 38% when degree of use of motorized patrols is at its high level. This improvement in FOC increases ROIIC 13%. The factor *a* (degree of use of high-tech devices) follows factor *d* in the significance. When factor *a* is at high level, DOC increases 28%. This improvement in DOC increases ROIIC 5%. The factor *b* (The degree of use of night-vision tools) increases DOC 10% and ROIIC 3%. When factor *e* (duty time of patrols) is at high level DOC increases 6% but improvement in ROIIC is only 1%. Other factors (degree of use of motorized patrols and determination of stationary or mobile characteristics of duty) have little effect on DOC. The factors *a,b* and *e* have negative effects on FOC.

There are mainly two kinds of interaction. These are: (1) interaction between factors that have positive effect on DOC (factors *a,b,e*) and factors that have positive effect on FOC (*c,d*) such as *a-c, b-d, a-d*. When *a,b,e* is high, longer time the zones will be under control and this prevents the occurrence of control of zones different times. (2) interaction between factors that have positive effect on DOC such as a-b, b-e. When one of these factors is high, longer time the zones will be under control and this will increase the probability of taking the same zones under control by security elements.

Commanders have to know that, when they increase the levels of more than one factor, the effect on performance measure will be less than total effect of each factor. For example, factor *a* improves ROIIC 5% and factor *d* improves 13%. When both factor are at high level, ROIIC increases 16% (note that it is 18% when we add effects of each factor).

CHAPTER 6

Alternatives and Border Security System Model in the Support of Decision-making Process

In Chapters 4 and 5, we have analyzed the system behavior, investigated effect of each security element on the performance measures and identified the significant factors. In this chapter, we develop different alternatives. These alternatives are the possible improvement methods. We know that improvement border security will cause financial costs. We evaluate these alternatives, compare and rank them by using ranking/ selection and multi-criteria decision-making procedures. The criteria are again our performance measures degree-of-controllability (DOC), frequency-of-controlling (FOC), ratio-of-illegal-infiltrations-caught (ROIIC) and cost.

Specifically, we will attempt to answer the following research questions:

- If coordination is established between security elements, how much does it affect the performance measures?
- How much do additional high-tech devices affect the performance measures?
- Which improvement method is the best considering different criteria?
- What is the effect of high mobility of patrols on the system performances?

6.1. Alternatives

1. *Benchmark system*: It is the existing system and this is included in comparisons to observe the effect of coordinated system.

2. *The border security system that all patrols are motorized*: When we analyzed the system in the previous chapters, we observed that the ROIIC increases as FOC increases. We also observed that FOC increases as motorized type of patrols increases. By including this improvement method, we will observe the effect of high mobility of patrols on the system performances.

3. *The system one more askarad and one more thermal camera added*: These high-tech devices make it possible to control wider borderline. We know that ROIIC increases as DOC increases. We include this improvement method to observe the effect of additional high-tech devices.

4. *The system with coordinated security elements*: In the system, sometimes overlaps occur since the security elements take control the same zones. We prevent these overlaps by making it possible to have better coordination between security elements. As a result, we expect the DOC performance measure increases.

5. *The system with coordination established and all patrols are motorized*: This is the combination of the second and forth alternatives.

6. *The system with coordination and one more askarad and thermal camera added:* Specifically, by including this alternative, we try to observe the effect of coordination when high-tech devices are increased. We expect that the degree-of-controllability increase.

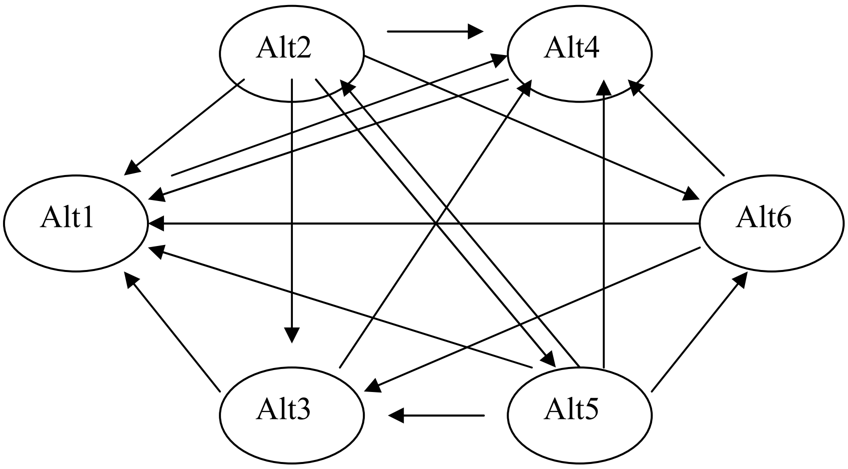
6.2. Evaluation of Alternatives by Using Ranking and Selection Procedures.

6.2.1. All Pairwise Comparisons

We first run the simulation model for each alternative design and obtain the results. The results for each alternative design are presented in Appendix E (Tables E.1-E.3) for each performance measure. Then, we make all pairwise comparisons to evaluate the alternatives. The results of all pairwise comparisons for the ROIIC performance measure are presented in Table 6.1. The results of all pairwise comparisons for DOC and FOC are presented in Appendix E (Tables E.4-E.5). We have 6 alternatives and 15 comparisons. We make each comparison with 99% degree of confidence interval. In Figure 6.1, the pairwise comparisons of alternatives and ranking of alternatives for ROIIC is presented. In this figure, arrows between alternatives display the comparison of two alternatives. If the alternative is at the beginning point of arrow, this alternative is better than the one that is at the end point of arrow. We draw these graphs for all performance measures and rank the alternatives according to their position either at the beginning or end point of the arrow. In Figures 6.2 and 6.3, the graph of comparisons and ranking of alternatives for DOC and FOC are presented.

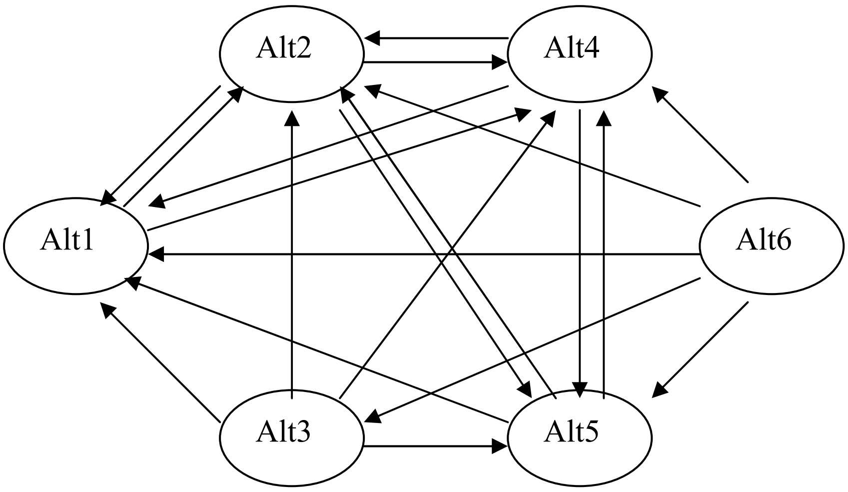
Table 6.1. Paired Samples Test of alternatives for ratio of illegal infiltrations caught

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ALT1 - ALT2	-.101083	1.57E-02	4.96E-03	-.117219	-8.49E-02	-20.359	9	.000
Pair 2	ALT1 - ALT3	-3.00E-02	1.09E-02	3.47E-03	-4.13E-02	-1.87E-02	-8.651	9	.000
Pair 3	ALT1 - ALT4	-5.97E-03	1.06E-02	3.37E-03	-1.69E-02	4.99E-03	-1.771	9	.110
Pair 4	ALT1 - ALT5	-.104150	1.04E-02	3.31E-03	-.114933	-9.33E-02	-31.388	9	.000
Pair 5	ALT1 - ALT6	-4.08E-02	1.07E-02	3.39E-03	-5.18E-02	-2.98E-02	-12.049	9	.000
Pair 6	ALT2 - ALT3	7.10E-02	1.33E-02	4.22E-03	5.73E-02	8.47E-02	16.803	9	.000
Pair 7	ALT2 - ALT4	9.51E-02	1.23E-02	3.90E-03	8.24E-02	.1077962	24.363	9	.000
Pair 8	ALT2 - ALT5	-3.06E-03	1.34E-02	4.25E-03	-1.68E-02	1.07E-02	-.722	9	.489
Pair 9	ALT2 - ALT6	6.02E-02	1.49E-02	4.71E-03	4.48E-02	7.55E-02	12.764	9	.000
Pair 10	ALT3 - ALT4	2.40E-02	7.74E-03	2.44E-03	1.61E-02	3.20E-02	9.825	9	.000
Pair 11	ALT3 - ALT5	-7.41E-02	7.74E-03	2.44E-03	-8.20E-02	-6.61E-02	-30.258	9	.000
Pair 12	ALT3 - ALT6	-1.08E-02	8.64E-03	2.73E-03	-1.97E-02	-1.94E-03	-3.963	9	.003
Pair 13	ALT4 - ALT5	-9.81E-02	1.07E-02	3.39E-03	-.109201	-8.71E-02	-28.939	9	.000
Pair 14	ALT4 - ALT6	-3.48E-02	8.45E-03	2.67E-03	-4.35E-02	-2.61E-02	-13.043	9	.000
Pair 15	ALT5 - ALT6	6.32E-02	7.03E-03	2.22E-03	5.60E-02	7.05E-02	28.435	9	.000



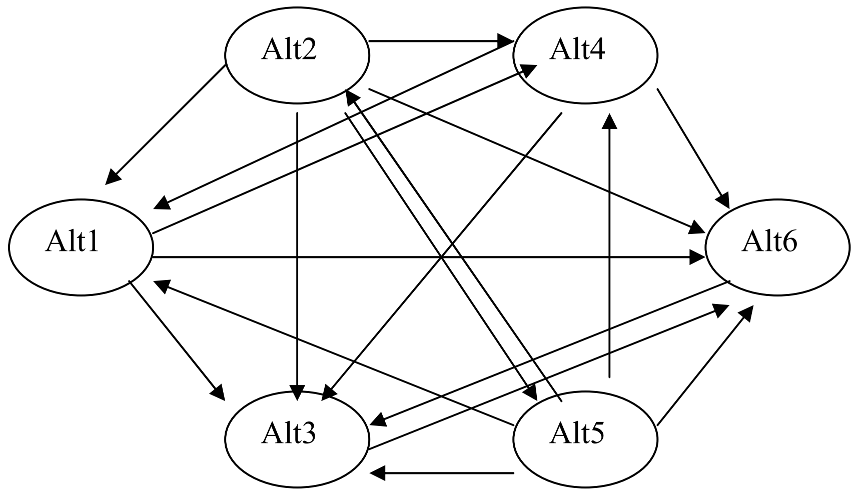
Ranking	Alternatives
1	Alt 2 ≅ Alt 5
2	Alt 6
3	Alt 3
4	Alt 1 ≅ Alt 4

Figure 6.1. The pairwise comparisons of alternatives and ranking of alternatives for ratio of illegal infiltrations caught performance measure



Ranking	Alternatives
1	Alt 6
2	Alt 3
3	Alt 5
4	Alt 1 ≅ Alt 2 ≅ Alt 4

Figure 6.2.The pairwise comparisons of alternatives and ranking of alternatives for DOC



Ranking	Alternatives
1	Alt 2 ≅ Alt 5
2	Alt 1 ≅ Alt 4
3	Alt 3 ≅ Alt 6

Figure 6.3. The pairwise comparisons of alternatives and ranking of alternatives for FOC

As seen in Figures 6.1-6.3, the second and the fifth alternatives are better than others for ROIIC and FOC. Alternative 6 and alternative 3 are in the second and third row for ROIIC, respectively. But they are the last for FOC. On the other hand, sixth alternative is the best and third alternative is the second for DOC. This shows that ranking of alternatives are not consistent for each performance measure.

We observe that when resources are increased coordination gets importance for both DOC and ROIIC. Because, the sixth alternative is better than the third alternative for both performance measures.

6.2.2. Rinott's Procedure

Although we made all pairwise comparisons, we couldn't rank the alternatives to find the best alternative. Then, we apply Rinott's ranking and selection procedure (1978). We first find the required number of replications for each alternative. The required numbers of replications are presented with results of alternatives in Appendix E (Tables E.1-E.3). Then we calculate the average of replications and select the alternative with the highest average as the best one.

In our study, we take $h_{10,\ 0.05} = 3.859$ and indifference amount value (d) for the ROIIC and DOC performance measures 0.005 whereas 10 for the FOC performance measure. The rankings of alternatives for each performance measure are presented in Tables 6.2-6.4.

Tables 6.2. Ranking of alternatives for ratio of illegal infiltrations caught

Ranking	**Alternatives**	**Values**
1	Alternative 5	0.634905
2	Alternative 2	0.631838
3	Alternative 6	0.571622
4	Alternative 3	0.560787
5	Alternative 4	0.536729
6	Alternative 1	0.530754

Table 6.3. Ranking of alternatives for degree of controllability

Ranking	**Alternatives**	**Values**
1	Alternative 6	0.29563
2	Alternative 3	0.284504
3	Alternative 5	0.226022
4	Alternative 4	0.223901
5	Alternative 2	0.221825
6	Alternative 1	0.21961

Table 6.4. Ranking of alternatives for frequency of controlling

Ranking	Alternatives	Values
1	Alternative 2	3153
2	Alternative 5	3146
3	Alternative 1	2046
4	Alternative 4	2045
5	Alternative 3	1877
6	Alternative 6	1865

As seen in Tables 6.2-6.4, alternative 6 is the best for DOC and alternative 3 follows it. But, alternative 6 is the last for FOC. Alternative 5 is the best for ROIIC and alternative 2 follows it. On the other hand, second alternative is the best for FOC and the fifth alternative follows it. All these results indicate that ranking of alternatives are not consistent for each performance measure.

We also observe that coordination is important to increase performance measures for both the DOC and ROIIC performance measures. Because, alternative 4 is better than alternative 1 and alternative 6 is better than alternative 3 for both ROIIC and DOC.

In both ranking and selection procedures, we observe that the ranking of alternatives are not consistent for each performance measure. Moreover, we have one more criterion that will effect the decision beyond the performance measures; cost of alternatives. Thus, we decide to apply multi-criteria decision-making procedures.

6.3. Implementation of Geometric Mean Technique for our Multi-criteria Decision-making Problem

We decide to implement geometric mean technique to our multi-criteria decision-making problem. Although there are many multi-criteria decision-making methods in the literature, we choose geometric mean technique. The geometric mean is the way to solve pairwise comparison matrices. Barzilai, et al. (1987) identified desired properties of this solution technique. We use geometric mean technique suggested by H.A. Eiselt (course handouts in Bilkent University 2001)

In the first step we construct our hierarchy tree as seen in Figure 6.5.

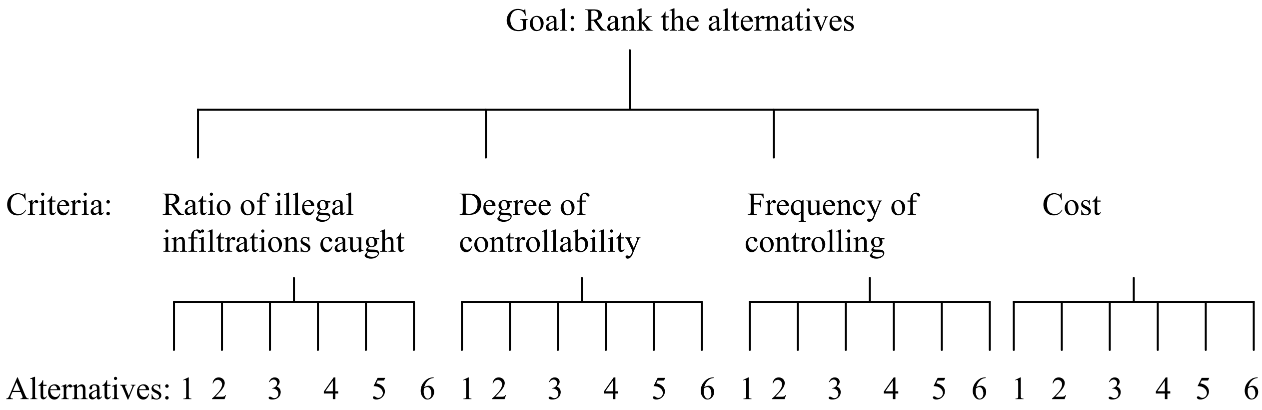


Figure 6.4. Hierarchy tree of alternatives and criteria

In the second step, the pairwise comparisons of alternatives are made for each criterion. Therefore, we construct our pairwise comparison matrices. In this step, since we know the border security system simulation results for each alternative, we can easily compare alternatives with each other for any criterion only by determining how much important the difference between the lowest and the highest score of alternatives. After consulting military experts, we give importance degree 5 "essentially more important" for the difference between the alternative with the lowest score and the alternative with the highest score. Then, we make pairwise comparisons of alternatives and we construct matrices according to values of simulation results. In Table 6.5, results of each alternative for each criterion are presented. The matrices that show the pairwise comparisons of alternatives are in Appendix E (Tables E.6a-E.6d).

Table 6.5. Results of each alternative for each criterion

criteria / alternatives	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling	Cost*
1	0.53075	0.21961	2046.64	0.04
2	0.63184	0.22183	3153.56	0.055
3	0.56079	0.2845	1877.88	0.075
4	0.53673	0.2239	2045.77	0.04
5	0.63491	0.22602	3146.43	0.055
6	0.57162	0.29256	1865.71	0.075

(*) Costs of alternatives are calculated as million $ for one-year time period (note that costs are calculated according to price of thermal camera (0.13 million $), price of askarad (0.24 million $) and amount of fuel needed for motorized patrols.)

In the third step, we construct pairwise comparison matrix for the criterions. We have four criterions, so we construct four by four pairwise comparison matrix. In this step, we consulted military experts for pairwise comparisons of criteria. The pairwise comparisons of criteria are presented in Table 6.6.

Table 6.6. Pairwise comparison matrix of criteria

Criteria	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling	cost
Ratio of illegal infiltrations caught	1.0000	2.5000	2.2500	1.2500
Degree of controllability	0.4000	1.0000	0.8600	0.4500
Frequency of controlling	0.4444	1.1628	1.0000	0.6000
cost	0.8000	2.2222	1.6667	1.0000

In the fourth step, we construct the utility matrix by taking geometric means of each row of matrices that we construct in the second step. For example, we calculate the geometric mean of first row of ROIIC matrix (Table E.6a in Appendix E) as 0.426605 and place it first row and first column of utility matrix and we calculate the geometric mean of second row of ROIIC matrix as 2.50834 and place it second row and first column of utility matrix. Meanwhile, we construct weight matrix by taking the geometric means of each row of pairwise comparison matrix of criteria and normalizing the results. In Tables 6.7-6.8 utility matrix and weight matrix (before and after normalization) are presented.

Table 6.7. Utility matrix

Alternatives	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling	cost
1	0.426605	0.534898	0.703763	2.369284
2	2.50834	0.579024	2.806936	1.077307
3	0.766993	2.520356	0.509854	0.391552
4	0.480913	0.625656	0.703144	2.370273
5	2.603455	0.675191	2.798679	1.077937
6	0.973224	3.032556	0.504556	0.391617

Table 6.8. Weight matrix

	Ratio of illegal infiltrations caught	Degree of controllability	Frequency of controlling	cost
Weights before normalization	1.628389	0.627253	0.746204	1.311996
Weights after normalization	0.37748	0.145405	0.172979	0.304136

In the fifth and the last step, we take the weight powers of each alternative row in the utility matrix and calculate values of each alternative. Then, we normalize the values.

The mathematical expression of calculation for alternative 1 is as follow:

$$V(alt1) = 0.426605^{0,37748} \times 0.534898^{0,145405} \times 0.703763^{0,172979} \times 2.369284^{0,304136} = 0,809794$$

Values of each alternative are presented in Table 6.9 and ranking of alternatives is presented in Table 6.10.

Table 6.9. Values of alternatives

	Before normalization	After normalization
V(alt1)	0.809794	0.126509
V(alt2)	1.59818	0.249674
V(alt3)	0.69252	0.108188
V(alt4)	0.866771	0.13541
V(alt5)	1.65686	0.258841
V(alt6)	0.776948	0.121378

Table 6.10. Ranking of alternatives

Ranking	**Alternatives**	**Values**
1	Alternative 5	0.258841
2	Alternative 2	0.249674
3	Alternative 4	0.13541
4	Alternative 1	0.126509
5	Alternative 6	0.121378
6	Alternative 3	0.108188

As seen in Table 6.10, alternative 5 is the best alternative. It shows us the importance of motorized type of patrols and coordination between security elements in the system. We also see the importance of coordination by observing alternative 4 in the third row of ranking. On the other hand, alternatives that need additional high-tech devices (alternatives 6 and 3) are not preferred because of their high costs. But, if new high-tech devices are added to the system, coordination must be established between security elements.

CHAPTER 7

Conclusion

7.1. Summary

In this thesis, we give brief information about how Turkey protects and control her land borders (border security system in Turkey). We first present a literature survey. Then, we define necessary components of the system and their interactions, which are all needed to develop a simulation model of border security system. We present our objectives to perform such a study and model development of the system. Our main aim is to find out possible ways of increasing border control and security along the land borders of Turkey. Therefore, we try to: (1) understand the behavior of the system, (2) observe the relationships between security elements and performance measures and relationships between performance measures, (3) find-out effect of each security element on the performance measures, (4) analyze factors that effect the performance measures, (5) investigate system responses, when changes made in the system or new resources added to the system, (6) evaluate different alternatives which improve the performance measures, by using ranking-selection and multi-criteria decision-making procedures. We try to achieve our objectives by modeling and analysis of operational activities of typical Border Company supported by Border Battalion via simulation. We analyze the outputs by using performance measures: (1) ratio-of-illegal-infiltrations-caught, (2) degree-of-controllability, (3) frequency-of-controlling.

7.2. Conclusions and Future Research Directions

1. The behavior of the system in terms of DOC, FOC and ROIIC are not uniform along the border. This is due to different use of security elements in different zones and different mobility characteristics of security elements. We can adjust DOC by using flexible use of security elements. It gives us the opportunity to control some part of our borders (critical zones) at high level. Ambushes are the most appropriate resource for controlling critical zones at high level. Therefore, training of ambushes must be given importance.
2. Patrols are the main security element for frequency of controlling the zones. Therefore, precautions for increasing the mobility of patrols must be taken (i.e., increasing the number of motorized patrols).
3. It is difficult to catch enemy special forces and terrorist type of infiltrations. To increase catching probability of these infiltrations, importance should be given to build physical obstacles along the borders. These obstacles increase infiltration time; so probability of catching illegal infiltrations increases.
4. There is a direct relation between DOC and ROIIC. But, ROIIC does not improve proportionally with DOC; that is by increasing the quantity of high-tech devices we don't necessarily prevent infiltrations on the borderlines. We know that increasing DOC needs more high-tech devices and this causes increase in the cost of border security. Therefore, appropriate quantity of high-tech devices must be identified for each border troop and ambushes must be used for controlling zones that cannot be controlled by high-tech devices.
5. There is also a direct relation between FOC and ROIIC. But, ROIIC does not improve proportionally with FOC. Therefore, border security planners must

identify the appropriate capacity of patrol and precautions such as increasing the mobility of patrols and building of physical obstacles must be taken to maximize ROIIC. Such precautions also deter the infiltrations along the border.

6. Each of security element (patrols, ambushes, thermal camera, askarad) has statistically significant effect on each performance measure with its existence when compared to its absence in the system.
7. We analyze the factors that affect the performance measures. All factors have significant effects on each of the performance measures. In Table 7.1, a summary is presented. In Table 7.2, factors and their descriptions are given.

Table 7.1 Factors affecting the performance measures.

Performance Measures	**Significant Factors**	**Improvement***
Ratio of illegal infiltrations caught	A, B, C, D, E	5%, 3%, 1%, 13%, 1%
Degree of controllability	A, B, C, D, E	28%, 10%, -1%, 1%, 6%
Frequency of controlling	A, B, C, D, E	-8%, -3%, 4%, 38%, -4%

(*) improvement indicates the change in performance measure when we change the factor from its low level to high level.

Table 7.2 Factors and their descriptions

Factor	Factor Description
A	The degree of use of high-tech devices
B	The degree of use of night-vision tools
C	Determination of stationary or moving characteristics of duty
D	The degree of use of motorized patrols
E	Duty time of patrols

According to these results, border troops have to use high-tech devices more frequently, increase the duty time of patrols, and increase mobility of all security elements along the borders to increase the security of land borders.

8. Another way of increasing border security is to establish coordination between security elements. Coordination increases degree of controllability by preventing control of same zones by two or more security elements at the same time.
9. We evaluate different alternatives by using ranking, selection and multi-criteria decision-making procedures to give an idea about how border security system simulation model supports the decision-making process before conducting real decisions. Alternative description and ranking of alternatives are presented in Table 7.3.

Table 7.3. Alternative description and ranking of alternatives

Ranking	Alternative	Alternative description	Value
1	Alternative 5	System that coordination is established and all patrols are motorized	0.258841
2	Alternative 2	System that all patrols are motorized	0.249674
3	Alternative 4	System that coordination is established between security elements	0.13541
4	Alternative 1	Benchmark system	0.126509
5	Alternative 6	System that coordination is established and one more askarad and one more thermal camera added	0.121378
6	Alternative 3	System with one more askarad and one more thermal camera	0.108188

When we look at the results, alternative 5 (system that coordination is established and all patrols are motorized) is preferred to other alternatives when we consider criterions: ratio-of-illegal-infiltrations-caught, degree-of-controllability, frequency-of-controlling and cost.

10. We know that additional security elements cause an increase in the cost of security of borders. On the other hand, like almost all countries in the world, we try to control our land borders at high level with limited resources. Therefore, before conducting real investments or changes to increase border security, we have to analyze utilities of additional resources or changes in the system in terms of performance measures and their costs for each border troop. Thus, the requirements of each border troop are evaluated more accurately and investments are made more useful.

Future Research Directions

Although the main task of border troops is protection and security of borders in their responsibility terrain, they have another tasks. They also perform some activities that support execution of their tasks. Furthermore, operational activities for control and security of borders may be analyzed under different conditions. Followings are the some topics that can be investigated by future studies.

1. Border security can be analyzed under situation of any strained relation with neighbor country before war, by considering the troops located very near to borders.
2. In our study, we analyze border security system under night conditions. The system can be analyzed under day conditions or under both night and day conditions.
3. One of the main tasks of border troops is collection of intelligence by close watching the terrain of neighbor country. The research can be conducted on this task of border troops.

4. We know that border troops are located in such a way that they execute their tasks best under peace and war conditions. But, by considering the developing technology and change in the regional threats, the locations of border troops at all levels can be analyzed.
5. Logistic activities of border troops can be analyzed.
6. Communication systems of border troops can be analyzed.

APPENDIX A

Confidence Intervals

Table A.1a. Confidence interval for degree of controllability of Border Company

C.I for degree of controllability of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	0.219926	0.003599	$1.2x10^{-5}$	0.22536
C.I with $\alpha = 0.1$	C.I low	0.218355	**Min**	**Median**
	C.I high	0.221496	0.214400	0.219491
C.I. with $\alpha = 0.05$	C.I low	0.217843	**# of reps**	
	C.I high	0.222008	10	
C.I. with $\alpha = 0.01$	C.I low	0.216716		
	C.I high	0.223135		

Table A.1b. Confidence interval for frequency of controlling of Border Company

C.I for frequency of controlling of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	2025	8.63111	74.496	2036.583
C.I with $\alpha = 0.1$	C.I low	2021.23	**Min**	**Median**
	C.I high	2028.76	2008.036	2025.595
C.I. with $\alpha = 0.05$	C.I low	2020.005	**# of reps**	
	C.I high	2029.99	10	
C.I. with $\alpha = 0.01$	C.I low	2017.303		
	C.I high	2032.696		

Table A.1c. Confidence interval for ratio of ill. inf. caught of Border Company

C.I for ratio of ill. inf. caught of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	0.530754	0.009157	$8.38x10^{-5}$	0.5402
C.I with $\alpha = 0.1$	C.I low	0.5267	**Min**	**Median**
	C.I high	0.5347	0.5126	0.533527
C.I. with $\alpha = 0.05$	C.I low	0.5254	**# of reps**	
	C.I high	0.5360	10	
C.I. with $\alpha = 0.01$	C.I low	0.5225		
	C.I high	0.5389		

Table A.2a. Confidence interval for degree of controllability of Border Company

C.I for degree of controllability of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	0.219926	0.081316	0.006612	0.40744
C.I with $\alpha = 0.1$	C.I low	0.184440	**Min**	**Median**
	C.I high	0.255411	0.04871	0.19374
C.I. with $\alpha = 0.05$	C.I low	0.17228		
	C.I high	0.2669		
C.I. with $\alpha = 0.01$	C.I low	0.1474		
	C.I high	0.2924		

Table A.2b. Confidence interval for frequency of controlling of Border Company

C.I for frequency of controlling of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	2025	668.71	447177.55	3021.2
C.I with $\alpha = 0.1$	C.I low	1733	**Min**	**Median**
	C.I high	2316	782.4	2003.7
C.I. with $\alpha = 0.05$	C.I low	1638		
	C.I high	2411		
C.I. with $\alpha = 0.01$	C.I low	1428		
	C.I high	2621		

Table A.2c. Confidence interval for ratio of ill. inf. caught of Border Company

C.I for ratio of ill. inf. caught of Border Company	**Average**	**Std.Dev.**	**Var**	**Max**
	0.5307	0.129745	0.01683	0.7509
C.I with $\alpha = 0.1$	C.I low	0.4600	**Min**	**Median**
	C.I high	0.5732	0.2377	0.5175
C.I. with $\alpha = 0.05$	C.I low	0.4415		
	C.I high	0.5917		
C.I. with $\alpha = 0.01$	C.I low	0.4009		
	C.I high	0.6323		

Table A.3a. Confidence interval for degree of controllability of 1st Border Platoon

C.I for degree of controllability of 1st Border Platoon	Average	Std.Dev.	Var	Max
	0.228424	0.004328	1.88×10^{-5}	0.234066
C.I with $\alpha = 0.1$	C.I low	0.226530	**Min**	**Median**
	C.I high	0.230316	0.223057	0.22797
C.I. with $\alpha = 0.05$	C.I low	0.2259	**# of reps**	
	C.I high	0.2309	10	
C.I. with $\alpha = 0.01$	C.I low	0.2245		
	C.I high	0.2322		

Table A.3b. Confidence interval for degree of controllability of 2nd Border Platoon

C.I for degree of controllability of 2nd Border Platoon	Average	Std.Dev.	Var	Max
	0.206546	0.007785	6.06×10^{-5}	0.215041
C.I with $\alpha = 0.1$	C.I low	0.203148	**Min**	**Median**
	C.I high	0.2099431	0.190449	0.206313
C.I. with $\alpha = 0.05$	C.I low	0.202040	**# of reps**	
	C.I high	0.211050	10	
C.I. with $\alpha = 0.01$	C.I low	0.199603		
	C.I high	0.213488		

Table A.3c. Confidence interval for degree of controllability of 3rd Border Platoon

C.I for degree of controllability of 3rd Border Platoon	Average	Std.Dev.	Var	Max
	0.204612	0.012994	0.000168857	0.231256
C.I with $\alpha = 0.1$	C.I low	0.198940	**Min**	**Median**
	C.I high	0.210282	0.189159	0.202072
C.I. with $\alpha = 0.05$	C.I low	0.197091	**# of reps**	
	C.I high	0.212131	10	
C.I. with $\alpha = 0.01$	C.I low	0.192023		
	C.I high	0.216199		

Table A.3d. Confidence interval for degree of controllability of 4th Border Platoon

C.I for degree of controllability of 4th Border Platoon	Average	Std.Dev.	Var	Max
	0.230055	0.007673	5.88×10^{-5}	0.240085
C.I with $\alpha = 0.1$	C.I low	0.2267064	**Min**	**Median**
	C.I high	0.233403	0.218417	0.227496
C.I. with $\alpha = 0.05$	C.I low	0.225614	**# of reps**	
	C.I high	0.234494	10	
C.I. with $\alpha = 0.01$	C.I low	0.223212		
	C.I high	0.236896		

Table A.4a. Confidence interval for frequency of controlling of 1st Border Platoon

C.I for frequency of controlling of 1st Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	2551.704	24.56574	603.475	2598.625
C.I with $\alpha = 0.1$	C.I low	2540.98	**Min**	**Median**
	C.I high	2562.42	2521.708	2554.167
C.I. with $\alpha = 0.05$	C.I low	2537.48	**# of reps**	
	C.I high	2565.91	10	
C.I. with $\alpha = 0.01$	C.I low	2529.79		
	C.I high	2573.79		

Table A.4b. Confidence interval for frequency of controlling of 2nd Border Platoon

C.I for frequency of controlling of 2nd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	1384.906	16.89975	285.60163	1413.222
C.I with $\alpha = 0.1$	C.I low	1377.53	**Min**	**Median**
	C.I high	1392.28	1356.667	1385.25
C.I. with $\alpha = 0.05$	C.I low	1375.12	**# of reps**	
	C.I high	1394.68	10	
C.I. with $\alpha = 0.01$	C.I low	1369.83		
	C.I high	1399.97		

Table A.4c. Confidence interval for frequency of controlling of 3rd Border Platoon

C.I for frequency of controlling of 3rd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	1355.389	25.32789	641.502141	1391.167
C.I with $\alpha = 0.1$	C.I low	1344.33	**Min**	**Median**
	C.I high	1366.44	1304.5	1353.778
C.I. with $\alpha = 0.05$	C.I low	1340.73	**# of reps**	
	C.I high	1370.04	10	
C.I. with $\alpha = 0.01$	C.I low	1332.80		
	C.I high	1377.97		

Table A.4d. Confidence interval for frequency of controlling of 4th Border Platoon

C.I for frequency of controlling of 4th Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	2478.054	31.22418	974.949	2522.5
C.I with $\alpha = 0.1$	C.I low	2464.42	**Min**	**Median**
	C.I high	2491.68	2444.833	2468.896
C.I. with $\alpha = 0.05$	C.I low	2459.98	**# of reps**	
	C.I high	2496.12	10	
C.I. with $\alpha = 0.01$	C.I low	2450.20		
	C.I high	2505.89		

Table A.5a. Confidence interval for ratio of ill. inf. caught of 1st Border Platoon

C.I for ratio of ill. inf. caught of 1st Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.62223	0.010393	0.000108	0.6346
C.I with $\alpha = 0.1$	C.I low	0.617695	**Min**	**Median**
	C.I high	0.626765	0.6013	0.62435
C.I. with $\alpha = 0.05$	C.I low	0.616216	**# of reps**	
	C.I high	0.628244	10	
C.I. with $\alpha = 0.01$	C.I low	0.613751		
	C.I high	0.630709		

Table A.5b. Confidence interval for ratio of ill. inf. caught of 2nd Border Platoon

C.I for ratio of ill. inf. caught of 2nd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.41682	0.014522	0.000211	0.4355
C.I with $\alpha = 0.1$	C.I low	0.410483	**Min**	**Median**
	C.I high	0.423157	0.3899	0.416
C.I. with $\alpha = 0.05$	C.I low	0.408416	**# of reps**	
	C.I high	0.425224	10	
C.I. with $\alpha = 0.01$	C.I low	0.404972		
	C.I high	0.428668		

Table A.5c. Confidence interval for ratio of ill. inf. caught of 3rd Border Platoon

C.I for ratio of ill. inf. caught of 3rd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.42527	0.010908	0.000119	0.4428
C.I with $\alpha = 0.1$	C.I low	0.42051	**Min**	**Median**
	C.I high	0.43003	0.4085	0.4248
C.I. with $\alpha = 0.05$	C.I low	0.418958	**# of reps**	
	C.I high	0.431582	10	
C.I. with $\alpha = 0.01$	C.I low	0.416371		
	C.I high	0.434169		

Table A.5d. Confidence interval for ratio of ill. inf. caught of 4th Border Platoon

C.I for ratio of ill. inf. caught of 4th Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.60951	0.014094	0.000199	0.6379
C.I with $\alpha = 0.1$	C.I low	0.603359	**Min**	**Median**
	C.I high	0.615661	0.5927	0.6058
C.I. with $\alpha = 0.05$	C.I low	0.601354	**# of reps**	
	C.I high	0.617666	10	
C.I. with $\alpha = 0.01$	C.I low	0.598011		
	C.I high	0.621009		

Table A.6a. Confidence interval for degree of controllability of 1st Border Platoon

C.I for degree of controllability of 1st Border Platoon	Average	Std.Dev.	Var	Max
	0.229801	0.078603	0.00617	0.40744
C.I with $\alpha = 0.1$	C.I low	0.1954	**Min**	**Median**
	C.I high	0.2641	0.13799	0.1994
C.I. with $\alpha = 0.05$	C.I low	0.1843		
	C.I high	0.2752		
C.I. with $\alpha = 0.01$	C.I low	0.1597		
	C.I high	0.29989		

Table A.6b. Confidence interval for degree of controllability of 2nd Border Platoon

C.I for degree of controllability of 2nd Border Platoon	Average	Std.Dev.	Var	Max
	0.206817	0.05906	0.003488	0.30644
C.I with $\alpha = 0.1$	C.I low	0.18104	**Min**	**Median**
	C.I high	0.23259	0.13983	0.20411
C.I. with $\alpha = 0.05$	C.I low	0.1726		
	C.I high	0.2409		
C.I. with $\alpha = 0.01$	C.I low	0.15414		
	C.I high	0.25948		

Table A.6c. Confidence interval for degree of controllability of 3rd Border Platoon

C.I for degree of controllability of 3rd Border Platoon	Average	Std.Dev.	Var	Max
	0.205268	0.086262	0.00744	0.37662
C.I with $\alpha = 0.1$	C.I low	0.1676	**Min**	**Median**
	C.I high	0.2429	0.04871	0.183445
C.I. with $\alpha = 0.05$	C.I low	0.15534		
	C.I high	0.25518		
C.I. with $\alpha = 0.01$	C.I low	0.12834		
	C.I high	0.28219		

Table A.6d. Confidence interval for degree of controllability of 4th Border Platoon

C.I for degree of controllability of 4th Border Platoon	Average	Std.Dev.	Var	Max
	0.230876	0.095265	0.0090754	0.40729
C.I with $\alpha = 0.1$	C.I low	0.1893	**Min**	**Median**
	C.I high	0.2724	0.11173	0.196955
C.I. with $\alpha = 0.05$	C.I low	0.1757		
	C.I high	0.2860		
C.I. with $\alpha = 0.01$	C.I low	0.1459		
	C.I high	0.3158		

Table A.7a. Confidence interval for frequency of controlling of 1st Border Platoon

C.I for frequency of controlling of 1st Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	2554	419.72	176165	3021,2
C.I with $\alpha = 0.1$	C.I low	2371.061	**Min**	**Median**
	C.I high	2737.388	1496.2	2676.45
C.I. with $\alpha = 0.05$	C.I low	2311.353		
	C.I high	2797.11		
C.I. with $\alpha = 0.01$	C.I low	2179.93		
	C.I high	2928.51		

Table A.7b. Confidence interval for frequency of controlling of 2nd Border Platoon

C.I for frequency of controlling of 2nd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	1384	228.85	52373	1558.3
C.I with $\alpha = 0.1$	C.I low	1285.036	**Min**	**Median**
	C.I high	1484.77	783.2	1445.35
C.I. with $\alpha = 0.05$	C.I low	1252.46		
	C.I high	1517.34		
C.I. with $\alpha = 0.01$	C.I low	1180.82		
	C.I high	1588.98		

Table A.7c. Confidence interval for frequency of controlling of 3rd Border Platoon

C.I for frequency of controlling of 3rd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	1355.389	229.10	52515	1554.4
C.I with $\alpha = 0.1$	C.I low	1255.38	**Min**	**Median**
	C.I high	1455.39	782	1460.85
C.I. with $\alpha = 0.05$	C.I low	1222.77		
	C.I high	1488.004		
C.I. with $\alpha = 0.01$	C.I low	1151.03		
	C.I high	1559.74		

Table A.7d. Confidence interval for frequency of controlling of 4th Border Platoon

C.I for frequency of controlling of 4th Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	2478.054	426.66	182040	2883
C.I with $\alpha = 0.1$	C.I low	2291.86	**Min**	**Median**
	C.I high	2664.24	1405	2703
C.I. with $\alpha = 0.05$	C.I low	2231.14		
	C.I high	2724.96		
C.I. with $\alpha = 0.01$	C.I low	2097.57		
	C.I high	2858.53		

Table A.8a. Confidence interval for ratio of ill. inf. caught of 1st Border Platoon

C.I for ratio of ill. inf. caught of 1st Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.612692	0.086094	0.007412	0.750947
C.I with $\alpha = 0.1$	C.I low	0.575121	**Min**	**Median**
	C.I high	0.650263	0.415205	0.616655
C.I. with $\alpha = 0.05$	C.I low	0.56287		
	C.I high	0.662514		
C.I. with $\alpha = 0.01$	C.I low	0.542451		
	C.I high	0.682933		

Table A.8b. Confidence interval for ratio of ill. inf. caught of 2nd Border Platoon

C.I for ratio of ill. inf. caught of 2nd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.408197	0.059784	0.003574	0.501923
C.I with $\alpha = 0.1$	C.I low	0.382108	**Min**	**Median**
	C.I high	0.434287	0.324786	0.393899
C.I. with $\alpha = 0.05$	C.I low	0.3736		
	C.I high	0.442794		
C.I. with $\alpha = 0.01$	C.I low	0.359421		
	C.I high	0.456973		

Table A.8c. Confidence interval for ratio of ill. inf. caught of 3rd Border Platoon

C.I for ratio of ill. inf. caught of 3rd Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.403534	0.089748	0.008055	0.57449
C.I with $\alpha = 0.1$	C.I low	0.364368	**Min**	**Median**
	C.I high	0.442699	0.237726	0.389129
C.I. with $\alpha = 0.05$	C.I low	0.351597		
	C.I high	0.45547		
C.I. with $\alpha = 0.01$	C.I low	0.330311		
	C.I high	0.476756		

Table A.8d. Confidence interval for ratio of ill. inf. caught of 4th Border Platoon

C.I for ratio of ill. inf. caught of 4th Border Platoon	**Average**	**Std.Dev.**	**Var**	**Max**
	0.586799	0.103741	0.010762	0.739563
C.I with $\alpha = 0.1$	C.I low	0.541527	**Min**	**Median**
	C.I high	0.632071	0.313889	0.601088
C.I. with $\alpha = 0.05$	C.I low	0.526764		
	C.I high	0.646834		
C.I. with $\alpha = 0.01$	C.I low	0.50216		
	C.I high	0.671438		

APPENDIX B

Results of 2^4 Factorial Design Experiments and ANOVA

Table B.1. Results, averages, variances of 10 replications for ratio of illegal infiltrations caught

	0	1	2	3	4	12	13	14
1	0	0.448087	0.130935	0.072066	0.056958	0.496378	0.469979	0.474891
2	0	0.429372	0.142152	0.082334	0.0625	0.497991	0.464605	0.42855
3	0	0.433307	0.139466	0.07812	0.050668	0.504337	0.463363	0.472713
4	0	0.44136	0.141461	0.078015	0.064222	0.497698	0.461601	0.472046
5	0	0.43423	0.139213	0.069696	0.067648	0.498796	0.468387	0.459366
6	0	0.437652	0.135028	0.073272	0.068949	0.5	0.458956	0.466901
7	0	0.444955	0.138722	0.067336	0.059843	0.50875	0.472036	0.462775
8	0	0.445204	0.139442	0.077943	0.047028	0.495003	0.472765	0.465556
9	0	0.427238	0.133599	0.065675	0.059072	0.494332	0.466989	0.468512
10	0	0.439906	0.141223	0.075072	0.065092	0.499174	0.458063	0.45374
Average	0	0.438131	0.138124	0.073953	0.060198	0.499246	0.465674	0.462505
Variance	0	4.93E-05	1.38E-05	2.84E-05	5.04E-05	1.90E-05	2.72E-05	0.000184

	23	24	34	123	124	134	234	1234
1	0.192151	0.184588	0.117174	0.516901	0.515058	0.484028	0.211646	0.512616
2	0.185851	0.176962	0.126311	0.520032	0.510769	0.491296	0.212563	0.537588
3	0.177659	0.171885	0.116074	0.514115	0.505498	0.501544	0.207034	0.537792
4	0.182097	0.17076	0.111463	0.518676	0.515241	0.484506	0.219484	0.519941
5	0.185714	0.16848	0.110305	0.52283	0.513219	0.490894	0.219291	0.540292
6	0.185535	0.167601	0.114854	0.524295	0.510275	0.484804	0.21728	0.534402
7	0.180613	0.164592	0.117404	0.519587	0.512203	0.489137	0.210475	0.529684
8	0.191681	0.178076	0.112725	0.501465	0.509987	0.484265	0.208048	0.524113
9	0.184074	0.180006	0.104732	0.522665	0.519328	0.4987	0.212655	0.538462
10	0.185173	0.178981	0.118948	0.524136	0.516557	0.486609	0.2085	0.532653
Average	0.185055	0.174193	0.114999	0.51847	0.512814	0.489578	0.212698	0.530754
Variance	2.00E-05	3.73E-05	3.34E-05	4.63E-05	1.56E-05	3.86E-05	2.09E-05	8.39E-05

Table B.2. Results, averages, variances of 10 replications for degree of controllability

	0	1	2	3	4	12	13	14
1	0	0.069018	0.081333	0.057195	0.042827	0.145658	0.121868	0.103541
2	0	0.06913	0.082125	0.059476	0.048665	0.144947	0.118432	0.111022
3	0	0.068959	0.084224	0.052582	0.041151	0.144601	0.117278	0.108363
4	0	0.069241	0.081836	0.058481	0.047637	0.145486	0.120429	0.112235
5	0	0.068903	0.083361	0.057782	0.046933	0.145082	0.11673	0.111932
6	0	0.069166	0.085441	0.057016	0.048425	0.144318	0.118101	0.108267
7	0	0.069045	0.081919	0.058438	0.040702	0.144366	0.115304	0.109941
8	0	0.06906	0.083485	0.04978	0.040034	0.143287	0.120525	0.110942
9	0	0.06887	0.082779	0.058207	0.036468	0.145325	0.115646	0.104907
10	0	0.068728	0.08267	0.053631	0.048638	0.145838	0.120366	0.108075
Average	0	0.069012	0.082917	0.056259	0.044148	0.144891	0.118468	0.108923
Variance	0	2.33E-08	1.55E-06	1.00E-05	1.97E-05	5.92E-07	5.09E-06	8.46E-06

Table B.2. (con't) Results, averages, variances of 10 replications for degree of controllability

	23	24	34	123	124	134	234	1234
1	0.131854	0.12621	0.091943	0.187203	0.178803	0.155931	0.161536	0.22264
2	0.132414	0.121654	0.088081	0.189805	0.173155	0.159931	0.170091	0.219036
3	0.13212	0.124421	0.094815	0.186944	0.179337	0.160242	0.172562	0.223063
4	0.129725	0.125804	0.101666	0.190915	0.178107	0.155173	0.165677	0.217875
5	0.131305	0.121155	0.091533	0.187944	0.176703	0.158473	0.163411	0.221235
6	0.127844	0.121208	0.099247	0.18597	0.178424	0.160534	0.174229	0.218774
7	0.130041	0.129148	0.083495	0.187385	0.188905	0.157011	0.168379	0.219083
8	0.130816	0.120284	0.085139	0.191626	0.187388	0.1516	0.162897	0.225416
9	0.132133	0.11801	0.097332	0.186539	0.178741	0.149081	0.15695	0.218195
10	0.130607	0.118521	0.095468	0.188057	0.178536	0.159707	0.166425	0.210782
Average	0.130886	0.122642	0.092872	0.188239	0.17981	0.156768	1.66E-01	0.21961
Variance	1.99E-06	1.31E-05	3.57E-05	3.64E-06	2.25E-05	1.52E-05	2.79E-05	1.57E-05

Table B.3. Results, averages, variances of 10 replications for frequency of controlling

	0	1	2	3	4	12	13	14
1	0	2391.393	64.17857	39.22619	32.28571	2231.845	2297.881	2347.238
2	0	2425.881	63.33333	38.96429	36.10714	2242.179	2304.643	2318.226
3	0	2397.988	62.47619	36.08333	29.35714	2237.155	2295.988	2331.262
4	0	2418.714	65.52381	38.70238	36.19048	2244.536	2291.476	2317.571
5	0	2422.857	67.33333	38.41667	38.7619	2251.393	2313.083	2315.345
6	0	2428.036	65.52381	38.5119	35.28571	2245.417	2301.405	2331.583
7	0	2415.119	64.65476	37.85714	26.20238	2227.726	2311.393	2326.512
8	0	2413.857	65.25	33.03571	31.04762	2247.333	2269.917	2312.762
9	0	2414	66.60714	37.7381	28.29762	2243.214	2283.762	2319.905
10	0	2396.619	65.17857	36.02381	36.67857	2251.929	2286.107	2327.321
Average	0	2412.446	65.00595	37.45595	33.02143	2242.273	2295.565	2324.773
Variance	0	165.0589	2.067941	3.634954	17.52191	62.71672	175.8651	106.0286

	23	24	34	123	124	134	234	1234
1	93.9881	99.33333	65.40476	2126.179	2147.405	2215.131	121.4167	2045.583
2	96.03571	93.5	60.61905	2103.774	2184.679	2204.012	125.631	2038.583
3	96.04762	91.07143	75.17857	2108.619	2161.786	2201.56	126.5238	2034.048
4	94.47619	98.54762	71.29762	2123.214	2168.286	2217.845	121.9762	2037.25
5	96.97619	96.25	65.44048	2127.75	2174.298	2226.679	120.6429	2054.333
6	94.10714	94.53571	72.88095	2123.964	2153.119	2209.083	129.5476	2046.536
7	99.13095	94.65476	57.79762	2127.714	2127.786	2208.595	128.4286	2045.75
8	96.78571	90.54762	60.77381	2098.488	2148.952	2220.44	124.0357	2030.798
9	99.34524	87.88095	69.78571	2123.798	2182.19	2223.298	119.2381	2034.048
10	94.90476	92.69048	66.2381	2122.69	2174.905	2213.881	118.1905	2099.476
Average	96.17976	93.90119	66.54167	2118.619	2162.34	2214.052	123.5631	2046.64
Variance	3.71071	12.74543	32.8141	115.7736	323.4316	68.07065	15.1085	397.1077

Table B.4. ANOVA results of ratio of illegal infiltrations caught performance measure

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	5.902	15	.393	9371.222	.000	.999	140568.325	1.000
Intercept	14.862	1	14.862	353987.534	.000	1.000	353987.534	1.000
A	5.468	1	5.468	130248.673	.000	.999	130248.673	1.000
B	.277	1	.277	6609.211	.000	.979	6609.211	1.000
C	5.851E-02	1	5.851E-02	1393.640	.000	.906	1393.640	1.000
D	3.573E-02	1	3.573E-02	850.936	.000	.855	850.936	1.000
A * B	4.081E-02	1	4.081E-02	971.977	.000	.871	971.977	1.000
A * C	9.365E-03	1	9.365E-03	223.052	.000	.608	223.052	1.000
B * C	2.308E-03	1	2.308E-03	54.976	.000	.276	54.976	1.000
A * B * C	4.182E-04	1	4.182E-04	9.961	.002	.065	9.961	.707
A * D	5.156E-03	1	5.156E-03	122.805	.000	.460	122.805	1.000
B * D	2.247E-03	1	2.247E-03	53.517	.000	.271	53.517	1.000
A * B * D	1.426E-04	1	1.426E-04	3.397	.067	.023	3.397	.225
C * D	5.377E-04	1	5.377E-04	12.807	.000	.082	12.807	.832
A * C * D	4.168E-04	1	4.168E-04	9.928	.002	.064	9.928	.705
B * C * D	6.141E-05	1	6.141E-05	1.463	.228	.010	1.463	.084
A * B * C * D	8.322E-05	1	8.322E-05	1.982	.161	.014	1.982	.118
Error	6.046E-03	144	4.198E-05					
Total	20.770	160						
Corrected Total	5.908	159						

Table B.5. ANOVA results of degree of controllability performance measure

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	.513	15	3.423E-02	3022.004	.000	.997	45330.063	1.000
Intercept	2.213	1	2.213	195350.340	.000	.999	195350.340	1.000
A	.150	1	.150	13235.362	.000	.989	13235.362	1.000
B	.217	1	.217	19125.367	.000	.993	19125.367	1.000
C	8.882E-02	1	8.882E-02	7840.755	.000	.982	7840.755	1.000
D	5.637E-02	1	5.637E-02	4976.137	.000	.972	4976.137	1.000
A * B	5.626E-04	1	5.626E-04	49.668	.000	.256	49.668	1.000
A * C	1.615E-04	1	1.615E-04	14.258	.000	.090	14.258	.876
B * C	4.759E-04	1	4.759E-04	42.009	.000	.226	42.009	1.000
A * B * C	3.182E-07	1	3.182E-07	.028	.867	.000	.028	.011
A * D	8.000E-05	1	8.000E-05	7.062	.009	.047	7.062	.520
B * D	1.942E-04	1	1.942E-04	17.144	.000	.106	17.144	.935
A * B * D	2.413E-05	1	2.413E-05	2.130	.147	.015	2.130	.129
C * D	1.825E-04	1	1.825E-04	16.110	.000	.101	16.110	.918
A * C * D	2.865E-05	1	2.865E-05	2.530	.114	.017	2.530	.158
B * C * D	9.037E-07	1	9.037E-07	.080	.778	.001	.080	.013
A * B * C * D	1.612E-05	1	1.612E-05	1.423	.235	.010	1.423	.081
Error	1.631E-03	144	1.133E-05					
Total	2.728	160						
Corrected Total	.515	159						

Table B.6. ANOVA results of frequency of controlling performance measure

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	188166272.855	15	12544418.190	133659.540	.000	1.000	2004893.103	1.000
Intercept	210047565.042	1	210047565.042	2238036.116	.000	1.000	2238036.116	1.000
A	187078750.963	1	187078750.963	1993305.665	.000	1.000	1993305.665	1.000
B	118446.945	1	118446.945	1262.041	.000	.898	1262.041	1.000
C	70200.459	1	70200.459	747.979	.000	.839	747.979	1.000
D	25682.573	1	25682.573	273.645	.000	.655	273.645	1.000
A * B	527385.757	1	527385.757	5619.243	.000	.975	5619.243	1.000
A * C	224075.951	1	224075.951	2387.507	.000	.943	2387.507	1.000
B * C	299.561	1	299.561	3.192	.076	.022	3.192	.209
A * B * C	1.624	1	1.624	.017	.896	.000	.017	.011
A * D	120716.000	1	120716.000	1286.217	.000	.899	1286.217	1.000
B * D	81.905	1	81.905	.873	.352	.006	.873	.049
A * B * D	333.644	1	333.644	3.555	.061	.024	3.555	.238
C * D	46.944	1	46.944	.500	.481	.003	.500	.031
A * C * D	239.168	1	239.168	2.548	.113	.017	2.548	.159
B * C * D	11.113	1	11.113	.118	.731	.001	.118	.014
A * B * C * D	.249	1	.249	.003	.959	.000	.003	.010
Error	13514.907	144	93.854					
Total	398227352.804	160						
Corrected Total	188179787.762	159						

APPENDIX C

2^5 Factorial Design Experiments and ANOVA Results

Table C.1 Factors and roles of factors for design points (2^5 factorial design)

	A	B	C	D	E	DESIGN POINTS
1	-1	-1	-1	-1	-1	0
2	+1	-1	-1	-1	-1	1
3	-1	+1	-1	-1	-1	2
4	-1	-1	+1	-1	-1	3
5	-1	-1	-1	+1	-1	4
6	-1	-1	-1	-1	+1	5
7	+1	+1	-1	-1	-1	12
8	+1	-1	+1	-1	-1	13
9	+1	-1	-1	+1	-1	14
10	+1	-1	-1	-1	+1	15
11	-1	+1	+1	-1	-1	23
12	-1	+1	-1	+1	-1	24
13	-1	+1	-1	-1	+1	25
14	-1	-1	+1	+1	-1	34
15	-1	-1	+1	-1	+1	35
16	-1	-1	-1	+1	+1	45
17	+1	+1	+1	-1	-1	123
18	+1	+1	-1	+1	-1	124
19	+1	+1	-1	-1	+1	125
20	+1	-1	+1	+1	-1	134
21	+1	-1	+1	-1	+1	135
22	+1	-1	-1	+1	+1	145
23	-1	+1	+1	+1	-1	234
24	-1	+1	+1	-1	+1	235
25	-1	+1	-1	+1	+1	245
26	-1	-1	+1	+1	+1	345
27	+1	+1	+1	+1	-1	1234
28	+1	+1	+1	-1	+1	1235
29	+1	+1	-1	+1	+1	1245
30	+1	-1	+1	+1	+1	1345
31	-1	+1	+1	+1	+1	2345
32	+1	+1	+1	+1	+1	12345

Table C.2 Factors and roles of factors for design points (2^4 factorial design)

	A	B	C	D	DESIGN POINTS
1	-1	-1	-1	-1	0000
2	+1	-1	-1	-1	1000
3	-1	+1	-1	-1	0100
4	-1	-1	+1	-1	0010
5	-1	-1	-1	+1	0001
6	+1	+1	-1	-1	1100
7	+1	-1	+1	-1	1010
8	+1	-1	-1	+1	1001
9	-1	+1	+1	-1	0110
10	-1	+1	-1	+1	0101
11	-1	-1	+1	+1	0011
12	+1	+1	+1	-1	1110
13	+1	+1	-1	+1	1101
14	+1	-1	+1	+1	1011
15	-1	+1	+1	+1	0111
16	+1	+1	+1	+1	1111

Table C.3. Results, averages, variances of 10 replications for ratio of illegal infiltrations caught(2^5 factorial design)

	0	1	2	3	4	5	12	13
1	0.50797	0.536617	0.530692	0.513751	0.572541	0.513905	0.565905	0.548488
2	0.501053	0.52656	0.530516	0.515435	0.589198	0.522333	0.555648	0.541438
3	0.516042	0.536174	0.537292	0.519805	0.584468	0.517958	0.567377	0.556981
4	0.520521	0.531957	0.527971	0.511848	0.590549	0.518022	0.558687	0.540664
5	0.515356	0.543608	0.543934	0.517749	0.575578	0.520066	0.566782	0.539574
6	0.519265	0.516999	0.528333	0.521803	0.585989	0.526824	0.56225	0.545607
7	0.519741	0.542768	0.517664	0.507774	0.580882	0.522749	0.551933	0.553551
8	0.513058	0.540492	0.53821	0.520423	0.580265	0.52929	0.550725	0.543191
9	0.513557	0.532507	0.536246	0.515289	0.593113	0.52332	0.555853	0.547284
10	0.517398	0.533445	0.52965	0.511763	0.592017	0.519298	0.558442	0.539643
average	0.514396	0.534113	0.532051	0.515564	0.58446	0.521377	0.55936	0.545642
variance	3.60E-05	6.38E-05	5.24E-05	1.97E-05	4.95E-05	2.04E-05	3.64E-05	3.59E-05
	14	15	23	24	25	34	35	45
1	0.621683	0.549613	0.539512	0.617623	0.537261	0.591942	0.513809	0.584705
2	0.63041	0.546005	0.535445	0.597333	0.532082	0.581651	0.518764	0.587682
3	0.610114	0.548146	0.539997	0.599934	0.532811	0.601709	0.514961	0.579899
4	0.602705	0.548475	0.533705	0.60588	0.524789	0.589195	0.521152	0.587827
5	0.616826	0.547832	0.528691	0.600651	0.544164	0.584094	0.52662	0.593229
6	0.611677	0.540487	0.532451	0.602472	0.537977	0.598482	0.501566	0.589565
7	0.602464	0.557782	0.531607	0.607548	0.538934	0.590952	0.521527	0.584476
8	0.61079	0.554501	0.530338	0.606764	0.527533	0.584367	0.529519	0.598648
9	0.601779	0.54547	0.533366	0.592507	0.54065	0.591005	0.505802	0.602252
10	0.610823	0.54419	0.527819	0.604938	0.539133	0.594167	0.515039	0.581539
average	0.611927	0.54825	0.533293	0.603565	0.535533	0.590756	0.516876	0.588982
variance	8.27E-05	2.46E-05	1.69E-05	4.61E-05	3.70E-05	4.04E-05	7.46E-05	5.19E-05
	123	124	125	134	135	145	234	235
1	0.572383	0.62232	0.554442	0.625325	0.545875	0.613222	0.60871	0.60871
2	0.571755	0.616273	0.555937	0.610711	0.561825	0.621058	0.606214	0.606214
3	0.566031	0.616575	0.562574	0.619024	0.551931	0.611462	0.608221	0.608221
4	0.557895	0.620097	0.567581	0.610586	0.551936	0.606909	0.588051	0.588051
5	0.560039	0.614412	0.569174	0.609829	0.550224	0.60871	0.599902	0.599902
6	0.552405	0.610345	0.55116	0.61804	0.558969	0.611551	0.606208	0.606208
7	0.562867	0.626164	0.552852	0.626177	0.549052	0.611393	0.61558	0.61558
8	0.549901	0.618793	0.583278	0.618231	0.559791	0.604901	0.598363	0.598363
9	0.564445	0.612706	0.551678	0.610304	0.5447	0.605043	0.602127	0.602127
10	0.572741	0.622987	0.564107	0.618977	0.553328	0.603394	0.602987	0.602987
average	0.563046	0.618067	0.561278	0.61672	0.552763	0.609764	0.603636	0.603636
variance	6.55E-05	2.44E-05	0.000104	3.78E-05	3.38E-05	2.71E-05	5.44E-05	5.44E-05
	245	345	1234	1235	1245	1345	2345	12345
1	0.595676	0.592379	0.629497	0.567117	0.622245	0.615114	0.598791	0.626212
2	0.603516	0.591412	0.629946	0.555298	0.623625	0.605845	0.612601	0.628514
3	0.601914	0.601153	0.619134	0.566773	0.62929	0.615721	0.611012	0.631216
4	0.587388	0.598494	0.615672	0.582047	0.626915	0.61334	0.607757	0.619378
5	0.603404	0.598485	0.631448	0.568425	0.623514	0.617603	0.605542	0.621916
6	0.600064	0.592854	0.634321	0.564686	0.618817	0.616836	0.609475	0.633777
7	0.602074	0.593052	0.631553	0.562625	0.618038	0.620876	0.606369	0.622015
8	0.607585	0.599967	0.617775	0.55741	0.624749	0.615681	0.605568	0.638464
9	0.590338	0.591205	0.62097	0.558843	0.621098	0.621054	0.611851	0.631596
10	0.607792	0.600131	0.622789	0.572089	0.631459	0.603523	0.600225	0.628534
average	0.599975	0.595913	0.625311	0.565531	0.623975	0.614559	0.606919	0.628162
variance	4.68E-05	1.64E-05	4.55E-05	6.14E-05	1.86E-05	3.32E-05	2.17E-05	3.52E-05

Table C.4. Results, averages, variances of 10 replications for degree of controllability (2^5 factorial design)

	0	1	2	3	4	5	12	13
1	0.197341	0.269063	0.218301	0.183315	0.195277	0.207598	0.276783	0.248519
2	0.193539	0.256755	0.219473	0.192881	0.19698	0.212855	0.276428	0.264755
3	0.190552	0.257957	0.215122	0.192056	0.193511	0.207762	0.279023	0.257564
4	0.196897	0.250744	0.220514	0.201088	0.191854	0.209489	0.282344	0.255813
5	0.201613	0.253922	0.222632	0.193822	0.193726	0.205358	0.280175	0.25905
6	0.191938	0.25266	0.216304	0.192719	0.194247	0.210408	0.283868	0.25791
7	0.191467	0.258895	0.211159	0.19196	0.197264	0.214408	0.277677	0.247639
8	0.193704	0.252944	0.211774	0.18362	0.193883	0.210991	0.273047	0.252503
9	0.192929	0.252185	0.220398	0.188516	0.200929	0.212034	0.281424	0.250273
10	0.192637	0.253962	0.213967	0.192012	0.19271	0.203459	0.273066	0.256422
average	0.194262	0.255909	0.216964	0.191199	0.195038	0.209436	0.278384	0.255045
variance	1.14E-05	2.83E-05	1.53E-05	2.65E-05	7.23E-06	1.17E-05	1.36E-05	2.82E-05
	14	15	23	24	25	34	35	45
1	0.257703	0.272148	0.21448	0.223347	0.231943	0.190995	0.201941	0.208117
2	0.260391	0.269645	0.219834	0.215485	0.230048	0.193472	0.20804	0.209839
3	0.260358	0.275073	0.215792	0.212581	0.236455	0.196405	0.201927	0.213966
4	0.264739	0.275265	0.208613	0.2206	0.232661	0.189171	0.208437	0.206238
5	0.260084	0.272785	0.217013	0.221026	0.239	0.191155	0.198824	0.217815
6	0.254765	0.262416	0.219573	0.22773	0.231614	0.192341	0.207571	0.208632
7	0.259967	0.26063	0.21817	0.216163	0.232043	0.197449	0.203307	0.213177
8	0.252563	0.269821	0.218925	0.226663	0.229171	0.1888	0.204073	0.206447
9	0.261869	0.268496	0.218713	0.211122	0.230765	0.187881	0.207735	0.218469
10	0.260777	0.27006	0.214263	0.217006	0.231748	0.199285	0.204702	0.20808
average	0.259322	0.269634	0.216538	0.219172	0.232545	0.192695	0.204656	0.211078
variance	1.22E-05	2.36E-05	1.18E-05	3.20E-05	8.87E-06	1.52E-05	1.05E-05	2.03E-05
	123	124	125	134	135	145	234	235
1	0.273957	0.282153	0.298008	0.258581	0.268143	0.273355	0.20964	0.222672
2	0.278161	0.282323	0.293481	0.255104	0.270281	0.263868	0.214956	0.231513
3	0.269145	0.277706	0.295304	0.247035	0.262435	0.272857	0.213598	0.221831
4	0.276788	0.278876	0.291855	0.259229	0.263296	0.273373	0.216246	0.233171
5	0.275508	0.283266	0.293255	0.26498	0.268735	0.275604	0.219197	0.228146
6	0.272032	0.2793	0.292876	0.255156	0.261247	0.265877	0.214664	0.231566
7	0.270823	0.283712	0.292464	0.259125	0.267298	0.264	0.214995	0.233911
8	0.273587	0.275278	0.289493	0.262866	0.26626	0.270143	0.213662	0.227664
9	0.276899	0.276838	0.283131	0.256107	0.270036	0.272217	0.215496	0.232832
10	0.271376	0.277471	0.285223	0.258374	0.266605	0.269993	0.211113	0.224538
average	0.273828	0.279693	0.291509	0.257656	0.266433	0.270129	0.214357	0.228784
variance	8.90E-06	8.80E-06	2.00E-05	2.39E-05	9.95E-06	1.75E-05	7.00E-06	2.03E-05
	245	345	1234	1235	1245	1345	2345	12345
1	0.232519	0.20452	0.277233	0.281529	0.301006	0.260002	0.230763	0.292859
2	0.240048	0.201451	0.270417	0.288332	0.29054	0.270364	0.228525	0.288539
3	0.23554	0.203109	0.270945	0.286966	0.298648	0.266915	0.234393	0.285082
4	0.235852	0.203583	0.277606	0.283649	0.297323	0.275027	0.238511	0.283206
5	0.230961	0.210936	0.268219	0.287921	0.292641	0.265667	0.230071	0.2876
6	0.231858	0.210657	0.272617	0.28674	0.291208	0.26064	0.233847	0.293653
7	0.232789	0.206193	0.274757	0.292681	0.293963	0.269413	0.226046	0.287139
8	0.237402	0.205357	0.270537	0.281928	0.291321	0.263775	0.227858	0.289023
9	0.242475	0.207528	0.275855	0.284176	0.290278	0.263831	0.231825	0.281052
10	0.234675	0.208571	0.275472	0.280198	0.286246	0.266806	0.233273	0.290628
average	0.235412	0.206191	0.273366	0.285412	0.293317	0.266244	0.231511	0.287878
variance	1.38E-05	1.02E-05	1.06E-05	1.45E-05	2.00E-05	2.08E-05	1.34E-05	1.60E-05

Table C.5. Results, averages, variances of 10 replications for frequency of controlling (2^5 factorial design)

	0	1	2	3	4	5	12	13
1	2022.702	1816.524	1955.536	2117.286	2843.286	1971.369	1837.464	1975.726
2	2033.917	1871.833	1993.714	2092.976	2849.131	1951	1820.917	1918.393
3	2026.048	1856.726	1971.607	2086.869	2863.762	1943.726	1815.917	1957.512
4	2020.405	1889.679	1974.44	2055.833	2852.536	1957.25	1819.893	1937.857
5	2008.595	1872.405	1955.702	2076.429	2875.667	1971.202	1842.94	1951.929
6	2040.905	1872.762	1978.548	2094.762	2839.619	1954.988	1804.452	1950.631
7	2039.036	1865.905	2000.679	2094.286	2809.607	1963.345	1830.095	1971.56
8	2033.905	1882.94	1982.81	2101.298	2829.607	1955.619	1831.262	1999.095
9	2032.048	1877.226	1959.488	2094.345	2846.714	1956.762	1827.417	1981.869
10	2032.31	1891.107	1973.44	2093.298	2863.25	1962.321	1849.56	1933.226
average	2028.987	1869.711	1974.596	2090.738	2847.318	1958.758	1827.992	1957.78
variance	94.39082	457.8927	231.9657	256.4114	352.23	73.78972	178.8189	603.9721
	14	15	23	24	25	34	35	45
1	2563.333	1801.631	2052.024	2721.655	1910.381	2895.905	2031.631	2762.155
2	2583.179	1812.119	2033.81	2768.464	1908.976	2870.238	2012.738	2750.619
3	2586.536	1801.536	2054.238	2804.024	1899.726	2871.464	2022.298	2727.881
4	2558.738	1801.274	2066.619	2763.024	1892.143	2920.083	2006.786	2769.94
5	2599.917	1812.298	2047.405	2750.607	1909.857	2913.071	2050	2734.071
6	2604.155	1823.893	2059.964	2719.976	1895.548	2888.512	2035.667	2742.464
7	2580.583	1831.214	2043.274	2753.536	1912.595	2878.512	2012.845	2710.667
8	2636.667	1805.048	2039.036	2730.048	1930.262	2936.548	2043.81	2747.69
9	2627.536	1793.833	2013.452	2803.321	1901.595	2926.202	2011.583	2730.5
10	2588.798	1824.155	2065.56	2763.048	1912.071	2878.56	2024.881	2781.774
average	2592.944	1810.7	2047.538	2757.77	1907.315	2897.91	2025.224	2745.776
variance	626.2001	150.2225	261.0087	883.8466	117.1842	591.448	217.0246	456.5963
	123	124	125	134	135	145	234	235
1	1949.476	2528.988	1742.857	2673.833	1890.202	2494.25	2882.94	1981.857
2	1899.821	2487.131	1762.262	2675.893	1883.417	2509.845	2851.071	1974.762
3	1919.631	2524.762	1741.905	2677.071	1894.667	2499.06	2838.702	2001.607
4	1918.893	2520.524	1753.036	2628.488	1878.048	2503.893	2833.619	1964.036
5	1930.095	2515.44	1767.107	2621.845	1888.44	2462.881	2816.048	1980.369
6	1907.893	2514.417	1732.036	2676.202	1912.476	2521.798	2802.667	1963.012
7	1942.524	2487.452	1753.464	2651.262	1877.643	2526.226	2826.524	1967.25
8	1913.071	2525.738	1774.81	2655	1904.917	2549.321	2821.476	1976.369
9	1916.274	2528.976	1769.476	2641.798	1888.131	2508.083	2839.131	1966.821
10	1931.917	2539.548	1778.214	2651.44	1892.679	2491.595	2839.702	1981.988
average	1922.96	2517.298	1757.517	2655.283	1891.062	2506.695	2835.188	1975.807
variance	238.8344	301.9999	236.5969	414.462	121.1364	534.1249	474.4883	135.4354
	245	345	1234	1235	1245	1345	2345	12345
1	2671.964	2806.405	2602.595	1867.238	2375.429	2568.667	2692.762	2494.202
2	2619.94	2813.702	2632.488	1836.905	2406.631	2576.214	2744.036	2561.429
3	2635.381	2818.821	2634.643	1850.524	2385.583	2565.976	2714.417	2499.917
4	2630.167	2797.083	2621.548	1835.345	2392.762	2532.417	2678.06	2523.679
5	2659.488	2804.262	2642.393	1845.571	2421.31	2589.81	2721.821	2540.179
6	2669.107	2778.143	2592.345	1829.107	2420.333	2601.702	2729.643	2488.988
7	2640.107	2821.19	2579.702	1838.595	2405.857	2574.81	2742.417	2488.964
8	2650.321	2801.536	2637.452	1880.31	2409.131	2585.571	2729.369	2495.917
9	2612.476	2820.25	2618.286	1860.226	2446.143	2563.107	2723.071	2558.607
10	2627.333	2791.56	2610.167	1860.333	2444.167	2573.857	2712.25	2497.595
average	2641.629	2805.295	2617.162	1850.415	2410.735	2573.213	2718.785	2514.948
variance	418.5741	193.3035	432.1646	266.4622	535.637	343.4779	427.9019	827.5634

Table C.6. ANOVA results for ratio of illegal infiltrations caught

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	.439	31	1.417E-02	336.233	.000	.973	10423.222	1.000
Intercept	105.361	1	105.361	2500125.165	.000	1.000	2500125.165	1.000
A	4.880E-02	1	4.880E-02	**1157.877**	**.000**	.801	1157.877	1.000
B	1.765E-02	1	1.765E-02	**418.839**	**.000**	.593	418.839	1.000
C	1.430E-03	1	1.430E-03	**33.926**	**.000**	.105	33.926	.999
D	.367	1	.367	**8707.032**	**.000**	.968	8707.032	1.000
E	1.050E-03	1	1.050E-03	**24.920**	**.000**	.080	24.920	.992
A * B	7.679E-05	1	7.679E-05	1.822	.178	.006	1.822	.109
A * C	1.563E-04	1	1.563E-04	3.708	.055	.013	3.708	.254
B * C	3.639E-06	1	3.639E-06	.086	.769	.000	.086	.013
A * B * C	2.594E-05	1	2.594E-05	.616	.433	.002	.616	.037
A * D	6.785E-04	1	6.785E-04	**16.100**	**.000**	.053	16.100	.921
B * D	6.218E-04	1	6.218E-04	**14.754**	**.000**	.049	14.754	.893
A * B * D	1.621E-05	1	1.621E-05	.385	.536	.001	.385	.026
C * D	6.923E-05	1	6.923E-05	1.643	.201	.006	1.643	.097
A * C * D	1.353E-04	1	1.353E-04	3.211	.074	.011	3.211	.214
B * C * D	8.871E-06	1	8.871E-06	.210	.647	.001	.210	.018
A * B * C * D	1.988E-04	1	1.988E-04	4.717	.031	.016	4.717	.338
A * E	1.546E-06	1	1.546E-06	.037	.848	.000	.037	.011
B * E	4.381E-05	1	4.381E-05	1.040	.309	.004	1.040	.059
A * B * E	5.772E-06	1	5.772E-06	.137	.712	.000	.137	.015
C * E	6.109E-06	1	6.109E-06	.145	.704	.001	.145	.016
A * C * E	6.650E-05	1	6.650E-05	1.578	.210	.005	1.578	.092
B * C * E	1.210E-04	1	1.210E-04	2.871	.091	.010	2.871	.186
A * B * C * E	3.528E-05	1	3.528E-05	.837	.361	.003	.837	.048
D * E	2.880E-04	1	2.880E-04	**6.833**	**.009**	.023	6.833	.509
A * D * E	4.572E-05	1	4.572E-05	1.085	.298	.004	1.085	.062
B * D * E	1.016E-04	1	1.016E-04	2.412	.122	.008	2.412	.151
A * B * D * E	5.471E-04	1	5.471E-04	**12.982**	**.000**	.043	12.982	.843
C * D * E	5.550E-05	1	5.550E-05	1.317	.252	.005	1.317	.076
A * C * D * E	1.335E-05	1	1.335E-05	.317	.574	.001	.317	.023
B * C * D * E	5.541E-05	1	5.541E-05	1.315	.252	.005	1.315	.076
A * B * C * D * E	1.983E-05	1	1.983E-05	.471	.493	.002	.471	.030
Error	1.214E-02	288	4.214E-05					
Total	105.812	320						
Corrected Total	.451	319						

Table C.7. ANOVA results for degree of controllability

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	.346	31	1.117E-02	697.354	.000	.987	21617.985	1.000
Intercept	18.835	1	18.835	1176183.286	.000	1.000	1176183.286	1.000
A	.290	1	.290	**18131.369**	**.000**	.984	18131.369	1.000
B	3.910E-02	1	3.910E-02	**2441.905**	**.000**	.895	2441.905	1.000
C	1.125E-03	1	1.125E-03	**70.275**	**.000**	.196	70.275	1.000
D	1.585E-04	1	1.585E-04	**9.898**	**.002**	.033	9.898	.710
E	1.468E-02	1	1.468E-02	**916.734**	**.000**	.761	916.734	1.000
A * B	2.400E-04	1	2.400E-04	**14.988**	**.000**	.049	14.988	.899
A * C	5.145E-06	1	5.145E-06	.321	.571	.001	.321	.023
B * C	3.534E-05	1	3.534E-05	2.207	.139	.008	2.207	.136
A * B * C	7.007E-05	1	7.007E-05	4.375	.037	.015	4.375	.310
A * D	4.523E-08	1	4.523E-08	.003	.958	.000	.003	.010
B * D	3.355E-07	1	3.355E-07	.021	.885	.000	.021	.011
A * B * D	5.940E-07	1	5.940E-07	.037	.847	.000	.037	.011
C * D	1.326E-05	1	1.326E-05	.828	.364	.003	.828	.048
A * C * D	5.412E-07	1	5.412E-07	.034	.854	.000	.034	.011
B * C * D	7.107E-06	1	7.107E-06	.444	.506	.002	.444	.028
A * B * C * D	9.507E-06	1	9.507E-06	.594	.442	.002	.594	.036
A * E	1.517E-04	1	1.517E-04	**9.472**	**.002**	.032	9.472	.686
B * E	4.056E-05	1	4.056E-05	2.533	.113	.009	2.533	.160
A * B * E	8.722E-06	1	8.722E-06	.545	.461	.002	.545	.033
C * E	4.418E-05	1	4.418E-05	2.759	.098	.009	2.759	.178
A * C * E	6.787E-07	1	6.787E-07	.042	.837	.000	.042	.012
B * C * E	1.031E-05	1	1.031E-05	.644	.423	.002	.644	.038
A * B * C * E	1.323E-06	1	1.323E-06	.083	.774	.000	.083	.013
D * E	5.459E-06	1	5.459E-06	.341	.560	.001	.341	.024
A * D * E	2.399E-05	1	2.399E-05	1.498	.222	.005	1.498	.087
B * D * E	5.959E-05	1	5.959E-05	3.721	.055	.013	3.721	.255
A * B * D * E	6.277E-06	1	6.277E-06	.392	.532	.001	.392	.026
C * D * E	1.113E-05	1	1.113E-05	.695	.405	.002	.695	.041
A * C * D * E	2.394E-07	1	2.394E-07	.015	.903	.000	.015	.011
B * C * D * E	1.705E-05	1	1.705E-05	1.064	.303	.004	1.064	.061
A * B * C * D * E	2.390E-06	1	2.390E-06	.149	.700	.001	.149	.016
Error	4.612E-03	288	1.601E-05					
Total	19.186	320						
Corrected Total	.351	319						

Table C.8. ANOVA results for frequency of controlling

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	47431035.845	31	1530033.414	4274.148	.000	.998	132498.580	1.000
Intercept	1689813508.866	1	1689813508.866	4720493.357	.000	1.000	4720493.357	1.000
A	2779263.955	1	2779263.955	**7763.873**	**.000**	.964	7763.873	1.000
B	299966.062	1	299966.062	**837.955**	**.000**	.744	837.955	1.000
C	467848.559	1	467848.559	**1306.935**	**.000**	.819	1306.935	1.000
D	43077344.631	1	43077344.631	**120336.545**	**.000**	.998	120336.545	1.000
E	567255.403	1	567255.403	**1584.628**	**.000**	.846	1584.628	1.000
A * B	3316.232	1	3316.232	**9.264**	**.003**	.031	9.264	.674
A * C	7497.898	1	7497.898	**20.945**	**.000**	.068	20.945	.976
B * C	7251.928	1	7251.928	**20.258**	**.000**	.066	20.258	.971
A * B * C	427.262	1	427.262	1.194	.276	.004	1.194	.068
A * D	171386.082	1	171386.082	**478.767**	**.000**	.624	478.767	1.000
B * D	18316.739	1	18316.739	**51.168**	**.000**	.151	51.168	1.000
A * B * D	685.983	1	685.983	1.916	.167	.007	1.916	.115
C * D	250.784	1	250.784	.701	.403	.002	.701	.041
A * C * D	105.773	1	105.773	.295	.587	.001	.295	.022
B * C * D	2366.996	1	2366.996	6.612	.011	.022	6.612	.492
A * B * C * D	188.162	1	188.162	.526	.469	.002	.526	.032
A * E	966.464	1	966.464	2.700	.101	.009	2.700	.173
B * E	3088.056	1	3088.056	**8.626**	**.004**	.029	8.626	.635
A * B * E	80.907	1	80.907	.226	.635	.001	.226	.019
C * E	18.437	1	18.437	.052	.821	.000	.052	.012
A * C * E	32.376	1	32.376	.090	.764	.000	.090	.013
B * C * E	49.182	1	49.182	.137	.711	.000	.137	.015
A * B * C * E	182.437	1	182.437	.510	.476	.002	.510	.032
D * E	21173.003	1	21173.003	**59.147**	**.000**	.170	59.147	1.000
A * D * E	593.985	1	593.985	1.659	.199	.006	1.659	.098
B * D * E	1061.719	1	1061.719	2.966	.086	.010	2.966	.194
A * B * D * E	44.644	1	44.644	.125	.724	.000	.125	.015
C * D * E	222.858	1	222.858	.623	.431	.002	.623	.037
A * C * D * E	30.643	1	30.643	.086	.770	.000	.086	.013
B * C * D * E	9.429	1	9.429	.026	.871	.000	.026	.011
A * B * C * D * E	9.258	1	9.258	.026	.872	.000	.026	.011
Error	103096.489	288	357.974					
Total	1737347641.200	320						
Corrected Total	47534132.334	319						

Table C.9. ANOVA results when factor *d* is with its low value

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	1306230.533	15	87082.036	382.658	.000	.976	5739.865	1.000
Intercept	596644242.756	1	596644242.756	2621786.150	.000	1.000	2621786.150	1.000
A	785160.429	1	785160.429	**3450.168**	**.000**	.960	3450.168	1.000
B	85017.181	1	85017.181	**373.584**	**.000**	.722	373.584	1.000
C	244881.514	1	244881.514	**1076.063**	**.000**	.882	1076.063	1.000
E	184621.774	1	184621.774	**811.269**	**.000**	.849	811.269	1.000
A * B	492.837	1	492.837	2.166	.143	.015	2.166	.131
A * C	4692.381	1	4692.381	**20.619**	**.000**	.125	20.619	.972
B * C	666.361	1	666.361	2.928	.089	.020	2.928	.188
A * B * C	24.173	1	24.173	.106	.745	.001	.106	.014
A * E	22.554	1	22.554	.099	.753	.001	.099	.014
B * E	264.184	1	264.184	1.161	.283	.008	1.161	.066
A * B * E	122.875	1	122.875	.540	.464	.004	.540	.033
C * E	56.548	1	56.548	.248	.619	.002	.248	.020
A * C * E	63.007	1	63.007	.277	.600	.002	.277	.021
B * C * E	7.771	1	7.771	.034	.854	.000	.034	.011
A * B * C * E	136.944	1	136.944	.602	.439	.004	.602	.036
Error	32770.320	144	227.572					
Total	597983243.609	160						
Corrected Total	1339000.853	159						

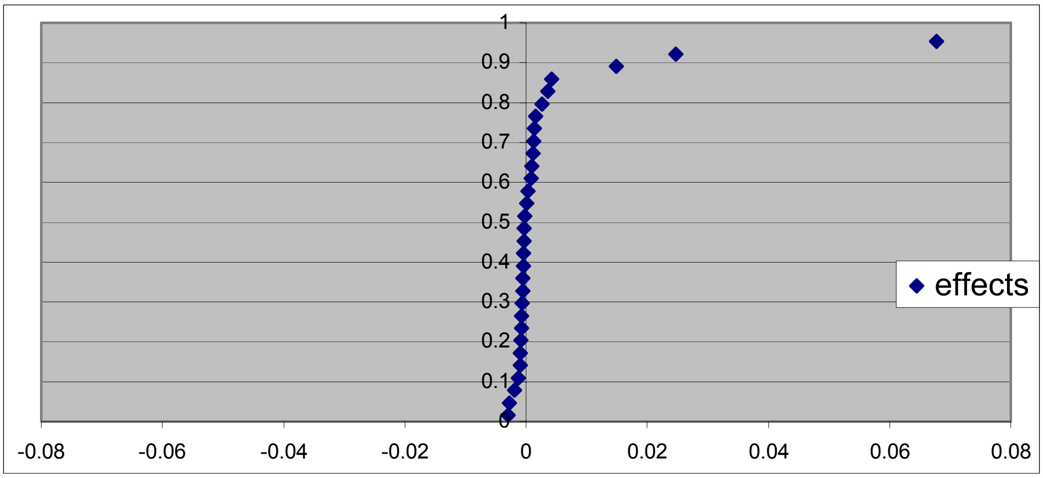
Table C.10. ANOVA results when factor *d* is with its high value

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	3047460.681	15	203164.045	415.999	.000	.977	6239.986	1.000
Intercept	1136246610.741	1	1136246610.741	2326580.768	.000	1.000	2326580.768	1.000
A	2165489.608	1	2165489.608	4434.061	**.000**	.969	4434.061	1.000
B	233265.620	1	233265.620	477.635	**.000**	.768	477.635	1.000
C	223217.829	1	223217.829	457.061	**.000**	.760	457.061	1.000
E	403806.633	1	403806.633	826.835	**.000**	.852	826.835	1.000
A * B	3509.378	1	3509.378	7.186	**.008**	.048	7.186	.529
A * C	2911.289	1	2911.289	5.961	**.016**	.040	5.961	.436
B * C	8952.563	1	8952.563	18.331	**.000**	.113	18.331	.951
A * B * C	591.251	1	591.251	1.211	.273	.008	1.211	.068
A * E	1537.895	1	1537.895	3.149	.078	.021	3.149	.206
B * E	3885.592	1	3885.592	7.956	**.005**	.052	7.956	.584
A * B * E	2.676	1	2.676	.005	.941	.000	.005	.010
C * E	184.746	1	184.746	.378	.539	.003	.378	.025
A * C * E	1.192E-02	1	1.192E-02	.000	.996	.000	.000	.010
B * C * E	50.840	1	50.840	.104	.747	.001	.104	.014
A * B * C * E	54.750	1	54.750	.112	.738	.001	.112	.014
Error	70326.169	144	488.376					
Total	1139364397.591	160						
Corrected Total	3117786.850	159						

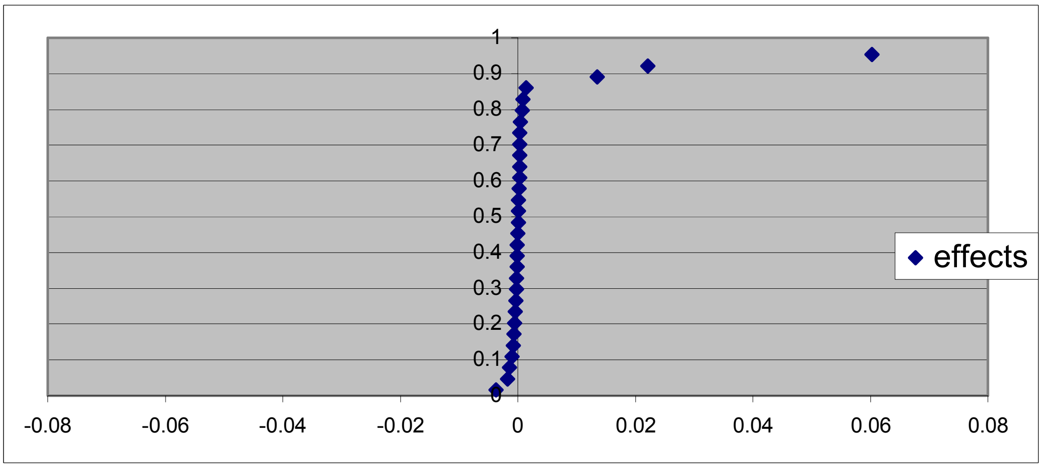
Table C.11. Analysis of normal P-P plot effects of performance measures

order(j)	ratio of illegal ınfıltratıons caught		degree of controllability		(j-0.5)/32
	Effect Estimate	Effect	Effect Estimate	Effect	
31	0.067725	4	0.060245	1	0.953125
30	0.024697	1	0.022109	2	0.921875
29	0.014854	2	0.013546	5	0.890625
28	0.004227	3	0.001408	4	0.859375
27	0.003623	5	0.000863	245	0.828125
26	0.002615	1245	0.000712	25	0.796875
25	0.001576	1234	0.000462	2345	0.765625
24	0.001398	13	0.000373	345	0.734375
23	0.00123	235	0.000359	235	0.703125
22	0.001127	245	0.000345	1234	0.671875
21	0.00093	34	0.00033	125	0.640625
20	0.000833	345	0.00028	1245	0.609375
19	0.000269	125	0.000261	45	0.578125
18	0.000139	15	0.000129	1235	0.546875
17	-0.00021	23	9.21E-05	135	0.515625
16	-0.00028	35	8.22E-05	134	0.484375
15	-0.00033	234	2.38E-05	14	0.453125
14	-0.00041	1345	-5.47E-05	1345	0.421875
13	-0.00045	124	-6.48E-05	24	0.390625
12	-0.0005	12345	-8.62E-05	124	0.359375
11	-0.00057	123	-0.00017	12345	0.328125
10	-0.00066	1235	-0.00025	13	0.296875
9	-0.00074	25	-0.0003	234	0.265625
8	-0.00076	145	-0.00041	34	0.234375
7	-0.00083	2345	-0.00055	145	0.203125
6	-0.00091	135	-0.00066	23	0.171875
5	-0.00098	12	-0.00074	35	0.140625
4	-0.0013	134	-0.00094	123	0.109375
3	-0.0019	45	-0.00138	15	0.078125
2	-0.00279	24	-0.00173	12	0.046875
1	-0.00291	14	-0.00375	3	0.015625

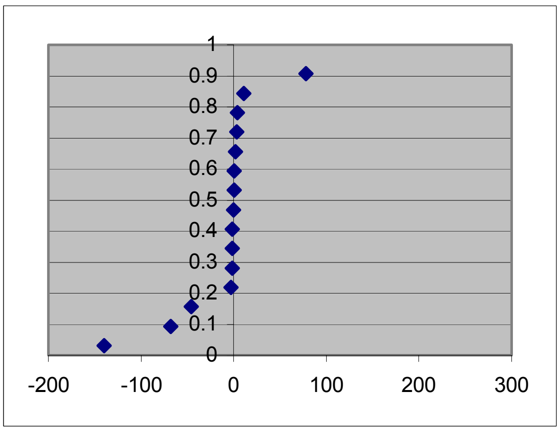
order(j)	Frequency of controlling when motorized patrol has low level		Frequency of controlling when motorized patrol has high level		(j-0.5)/16
	Effect Estimate	Effect	Effect Estimate	Effect	
15	78.24345	3	74.70238	3	0.90625
14	10.83095	13	14.96042	23	0.84375
13	4.081547	23	9.366667	12	0.78125
12	3.510119	12	8.53125	13	0.71875
11	1.850298	1234	6.200595	14	0.65625
10	0.777381	123	3.844643	123	0.59375
9	0.750893	14	2.149107	34	0.53125
8	-0.44077	234	1.16994	1234	0.46875
7	-1.18899	34	-0.01726	134	0.40625
6	-1.25506	134	-0.25863	124	0.34375
5	-1.75268	124	-1.12738	234	0.28125
4	-2.56994	24	-9.85595	24	0.21875
3	-46.1024	2	-76.3652	2	0.15625
2	-67.9378	4	-100.475	4	0.09375
1	-140.104	1	-232.674	1	0.03125



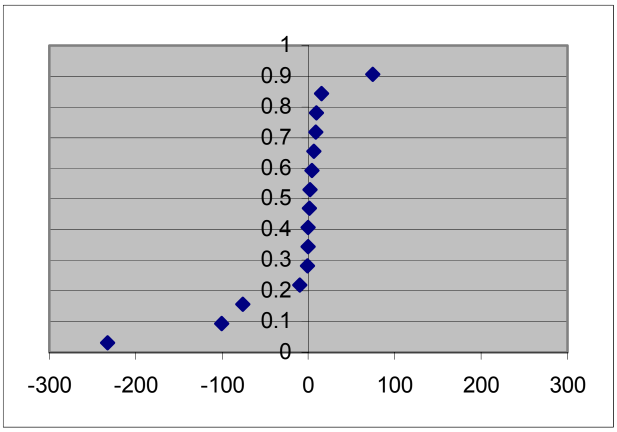
a) Normal probability plot of ratio of illegal infiltrations caught



b) Normal probability plot of degree of controllability



c) Normal probability plot of frequency of controlling (factor *d* low)

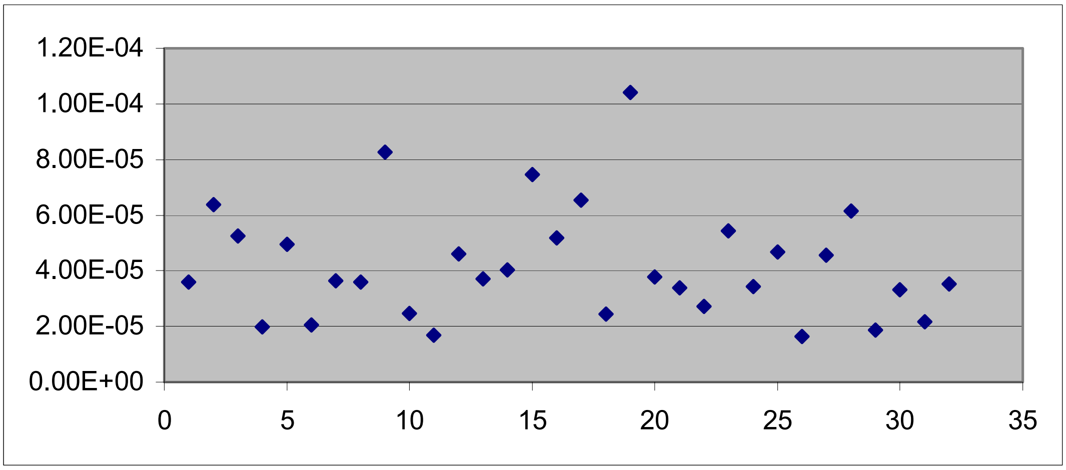


d) Normal probability plot of frequency of controlling (factor *d* high)

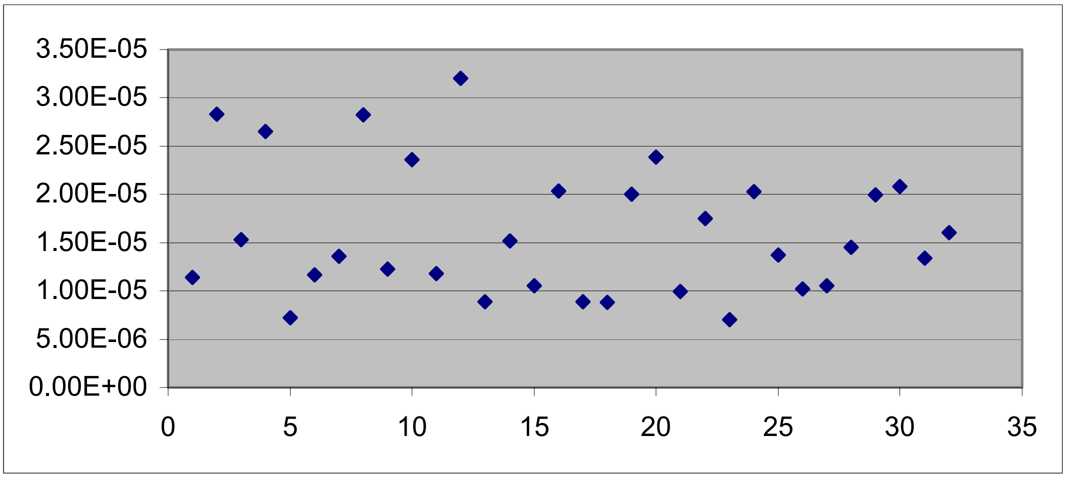
Figure C.1. Normal probability plots of each performance measure

APPENDIX D

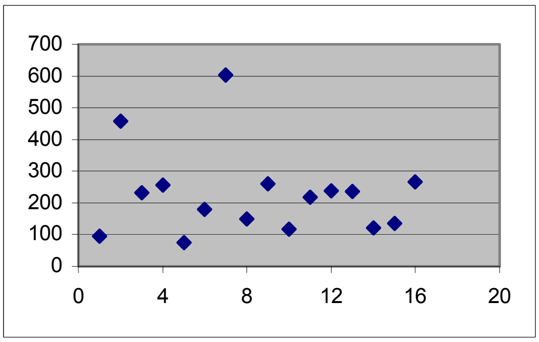
Assumptions of ANOVA



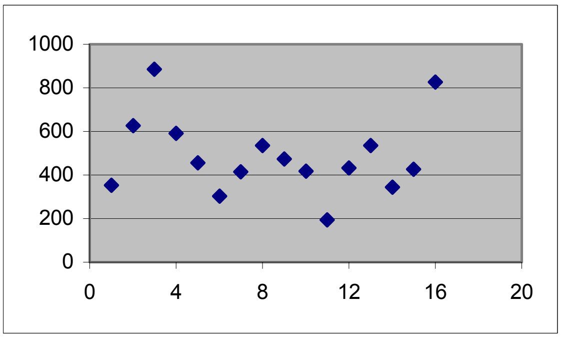
a) Scatter plot of variances of ratio of illegal infiltrations caught



b) Scatter plot of variances of degree of controllability



c) Scatter plot of variances
of frequency of controlling
(factor *d* low)



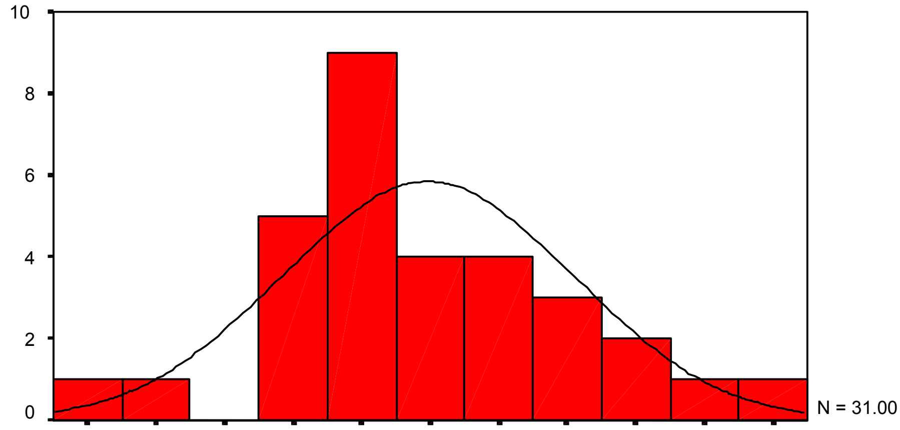
d) Scatter plot of variances
of frequency of controlling
(factor *d* high)

Figure D.1 Scatter plot of variances

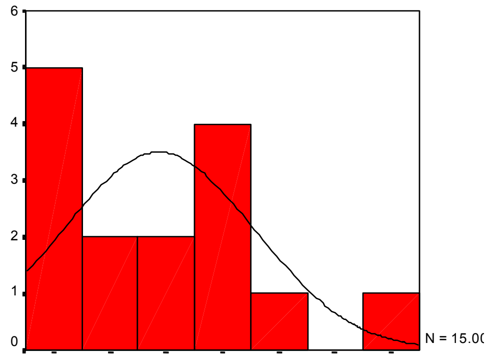
Table D.1. Residual analysis for performance measures

	Ratio of illegal infiltrations caught			Degree of controllability		
	y	y^	e=y-y^	y	y^	e=y-y^
1	0.534113	0.538746	-0.00463	0.255909	0.258323	-0.00241
2	0.532051	0.528783	0.003268	0.216964	0.217427	-0.00046
3	0.515564	0.517981	-0.00242	0.191199	0.189838	0.001361
4	0.58446	0.586464	-0.002	0.195038	0.194996	4.2E-05
5	0.521377	0.516662	0.004715	0.209436	0.209894	-0.00046
12	0.55936	0.559005	0.000356	0.278384	0.278702	-0.00032
13	0.545642	0.542973	0.00267	0.255045	0.254573	0.000472
14	0.611927	0.610866	0.001061	0.259322	0.259731	-0.00041
15	0.54825	0.546884	0.001366	0.269634	0.269109	0.000525
23	0.533293	0.53301	0.000284	0.216538	0.213677	0.002861
24	0.603565	0.601143	0.002423	0.219172	0.218835	0.000337
25	0.535533	0.536921	-0.00139	0.232545	0.233733	-0.00119
34	0.590756	0.590691	6.6E-05	0.192695	0.191246	0.001449
35	0.516876	0.520889	-0.00401	0.204656	0.206144	-0.00149
45	0.588982	0.590802	-0.00182	0.211078	0.211302	-0.00022
123	0.563046	0.563232	-0.00019	0.273828	0.274952	-0.00112
124	0.618067	0.620315	-0.00225	0.279693	0.28011	-0.00042
125	0.561278	0.561913	-0.00063	0.291509	0.289488	0.002021
134	0.61672	0.615093	0.001628	0.257656	0.255981	0.001675
135	0.552763	0.551111	0.001653	0.266433	0.265359	0.001074
145	0.609764	0.609974	-0.00021	0.270129	0.270517	-0.00039
234	0.603636	0.60537	-0.00173	0.214357	0.215085	-0.00073
235	0.54002	0.541148	-0.00113	0.228784	0.229983	-0.0012
245	0.599975	0.600251	-0.00028	0.235412	0.235141	0.000271
345	0.595913	0.595029	0.000885	0.206191	0.207552	-0.00136
1234	0.625311	0.624542	0.000769	0.273366	0.27636	-0.00299
1235	0.565531	0.56614	-0.00061	0.285412	0.285738	-0.00033
1245	0.623975	0.624653	-0.00068	0.293317	0.290896	0.002421
1345	0.614559	0.614201	0.000359	0.266244	0.266767	-0.00052
2345	0.606919	0.604478	0.002441	0.231511	0.231391	0.00012
12345	0.628162	0.62888	-0.00072	0.287878	0.287146	0.000732

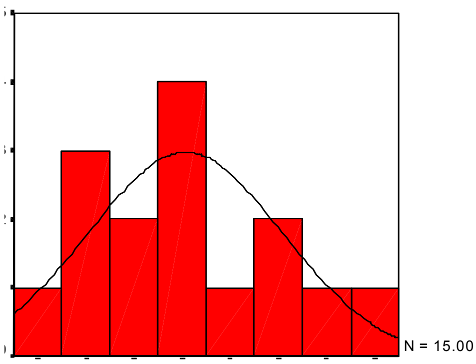
	Frequency of controlling (patrol type with low level)			Frequency of controlling (patrol type with high level)		
	y	y^	e=y-y^	y	y^	e=y-y^
1	1869.711	1873.085	-3.37429	2592.944	2596.875	-3.93095
2	1974.596	1977.915	-3.31857	2757.77	2737.915	19.85524
3	2090.738	2091.085	-0.3469	2897.91	2907.125	-9.21548
4	1958.758	1956.915	1.843333	2745.776	2748.085	-2.30881
12	1827.992	1827.085	0.906667	2517.298	2515.275	2.022619
13	1957.78	1961.915	-4.13524	2655.283	2665.765	-10.4817
14	1810.7	1806.085	4.615	2506.695	2506.725	-0.02976
23	2047.538	2045.085	2.453095	2835.188	2836.725	-1.53691
24	1907.315	1910.915	-3.59952	2641.629	2647.765	-6.13643
34	2025.224	2024.085	1.13881	2805.295	2797.275	8.020238
123	1922.96	1915.915	7.044524	2617.162	2614.085	3.076905
124	1757.517	1760.085	-2.56833	2410.735	2425.125	-14.3905
134	1891.062	1894.915	-3.85309	2573.213	2555.915	17.2981
234	1975.807	1978.085	-2.27786	2718.785	2726.875	-8.09048
1234	1850.415	1848.915	1.500476	2514.948	2504.235	10.71262



a) Histogram of residuals compared with normal for degree of controllability

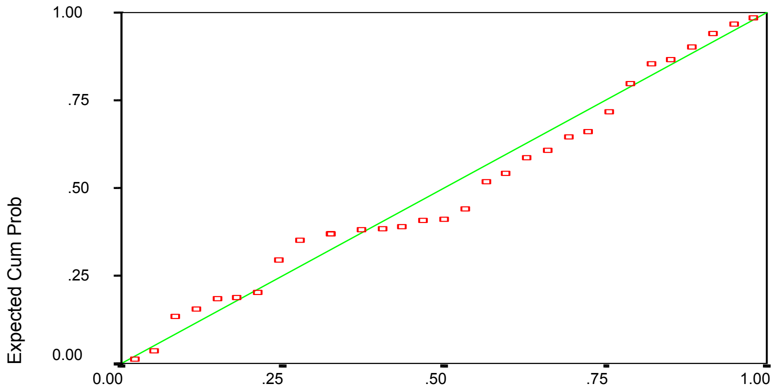


b) Histogram of residuals for FOC(factor *d* low)

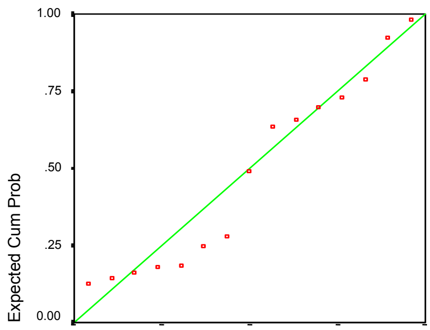


c) Histogram of residuals for FOC(factor *d* high)

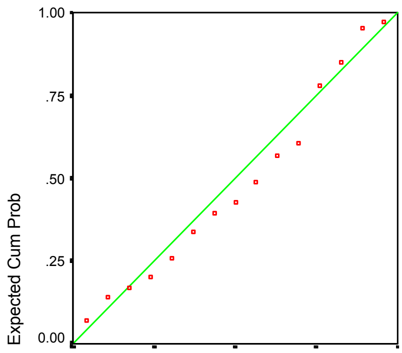
Figure D.2. Histogram of residuals



a) Normal P-P of residuals for degree of controllability

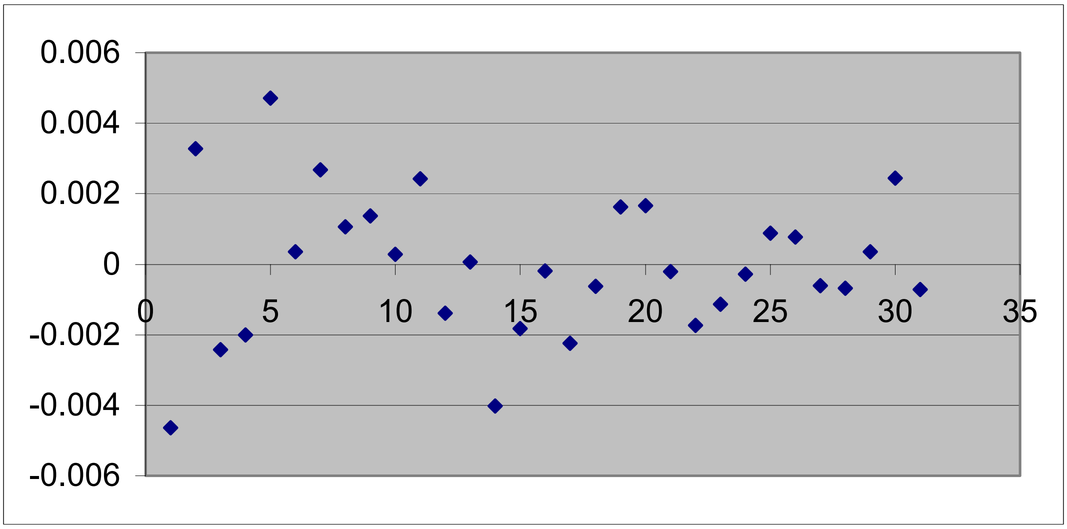


b) Normal P-P of residuals for FOC

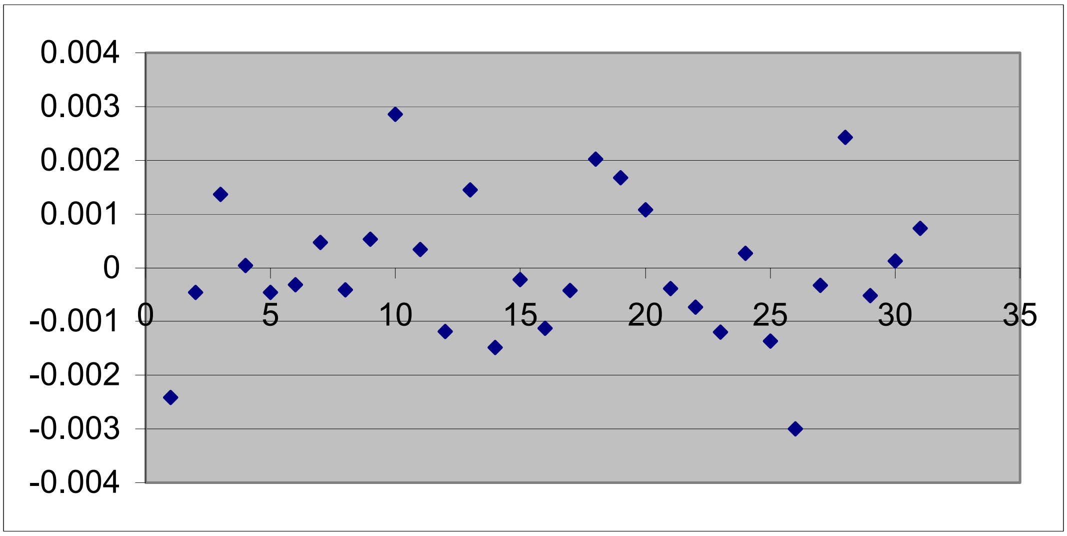


c) Normal P-P of residuals for FOC

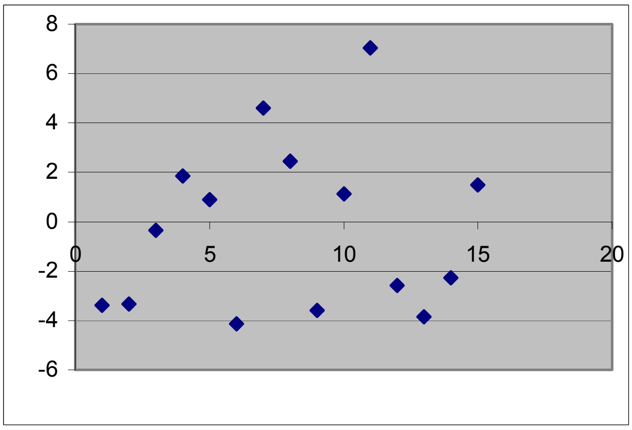
Figure D.3. Normal P-P of residuals



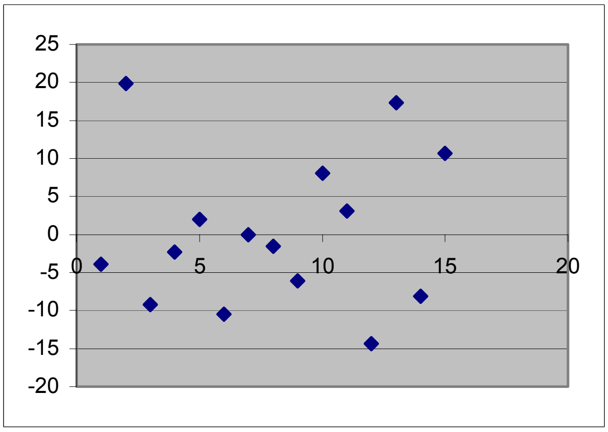
a) Scatter plot of residuals for ratio of illegal infiltrations caught.



b) Scatter plot of residuals for degree of controllability



c) Scatter plot of residuals for FOC (factor *d* low)



d) Scatter plot of residuals for (FOC) (factor *d* high)

Figure D.4. Scatter plot of residuals

APPENDIX E

Results of Alternatives and Pairwise Comparisons of Alternatives

Table E.1. Results of 10 replications for ratio of illegal infiltrations caught

	Alternative1	Alternative2	Alternative3	Alternative4	Alternative5	Alternative6
1	0.512616	0.647059	0.565512	0.537676	0.636602	0.573177
2	0.537588	0.64261	0.560351	0.534868	0.63969	0.56649
3	0.537792	0.646491	0.565972	0.54666	0.626952	0.564944
4	0.519941	0.625775	0.561998	0.539209	0.63365	0.566028
5	0.540292	0.636319	0.560534	0.529421	0.639105	0.567309
6	0.534402	0.614714	0.570262	0.531103	0.640259	0.577602
7	0.529684	0.62064	0.558047	0.532788	0.640599	0.572894
8	0.524113	0.636022	0.546502	0.528124	0.631964	0.573784
9	0.538462	0.623279	0.555462	0.544608	0.631964	0.577882
10	0.532653	0.625471	0.563234	0.542829	0.628264	0.576108
Average	0.530754	0.631838	0.560787	0.536729	0.634905	0.571622
Variance	7.55E-05	1.17E-04	3.87E-05	3.83E-05	2.31E-05	2.25E-05
Rinott Ni	6.70	8.35	4.80	4.78	3.71	3.66

Table E.2. Results of 10 replications for degree of controllability

	Alternative1	Alternative2	Alternative3	Alternative4	Alternative5	Alternative6
1	0.22264	0.217991	0.290523	0.21905	0.22761	0.291102
2	0.219036	0.216447	0.274816	0.229664	0.224461	0.296353
3	0.223063	0.222325	0.284535	0.222797	0.222789	0.290295
4	0.217875	0.216381	0.296514	0.223085	0.22363	0.289109
5	0.221235	0.220999	0.286403	0.226565	0.233248	0.294565
6	0.218774	0.22625	0.280381	0.226967	0.223173	0.296159
7	0.219083	0.22495	0.283159	0.218191	0.227942	0.294094
8	0.225416	0.226096	0.287931	0.220596	0.233121	0.29458
9	0.218195	0.217992	0.28916	0.223861	0.222776	0.284302
10	0.210782	0.22882	0.271615	0.228232	0.221468	0.295075
Average	0.21961	0.221825	0.284504	0.223901	0.226022	0.292563
Variance	1.57E-05	2.06E-05	5.51E-05	1.53E-05	1.85E-05	1.46E-05
Rinott Ni	3.06	3.50	5.73	3.02	3.32	2.95

Table E.3. Results of 10 replications for frequency of controlling

	Alternative1	Alternative2	Alternative3	Alternative4	Alternative5	Alternative6
1	2045.583	3182.143	1861.524	2049.226	3154.821	1866.202
2	2038.583	3171.393	1897.238	2033.94	3145.833	1857.821
3	2034.048	3146.143	1877.929	2041.5	3164.202	1857.06
4	2037.25	3165.321	1853.571	2060.786	3152.583	1869.131
5	2054.333	3149.607	1883.345	2038.202	3133.31	1873.929
6	2046.536	3123.012	1889.452	2021.381	3154.833	1854.643
7	2045.75	3141.262	1884.595	2055.012	3152.083	1881.31
8	2030.798	3145.726	1875.202	2062.798	3099.179	1861.964
9	2034.048	3166.536	1855.821	2058.988	3164.881	1886.595
10	2099.476	3144.429	1900.143	2035.845	3142.56	1848.476
Average	2046.64	3153.557	1877.882	2045.768	3146.429	1865.713
Variance	397.1077	304.6123	270.1598	188.4726	365.2591	147.7339
Rinott Ni	7.69	6.73	6.34	5.29	7.37	4.69

Table E.4. Paired samples test of alternatives for degree of controllability

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ALT1 - ALT2	-2.21E-03	6.65E-03	2.10E-03	-9.05E-03	4.62E-03	-1.053	9	.320
Pair 2	ALT1 - ALT3	-6.48E-02	6.35E-03	2.00E-03	-7.14E-02	-5.83E-02	-32.305	9	.000
Pair 3	ALT1 - ALT4	-4.29E-03	6.87E-03	2.17E-03	-1.13E-02	2.77E-03	-1.974	9	.080
Pair 4	ALT1 - ALT5	-6.41E-03	3.54E-03	1.11E-03	-1.00E-02	-2.77E-03	-5.725	9	.000
Pair 5	ALT1 - ALT6	-7.29E-02	5.66E-03	1.79E-03	-7.87E-02	-6.71E-02	-40.730	9	.000
Pair 6	ALT2 - ALT3	-6.26E-02	1.04E-02	3.31E-03	-7.34E-02	-5.19E-02	-18.907	9	.000
Pair 7	ALT2 - ALT4	-2.07E-03	5.96E-03	1.88E-03	-8.20E-03	4.05E-03	-1.101	9	.300
Pair 8	ALT2 - ALT5	-4.19E-03	6.03E-03	1.90E-03	-1.04E-02	2.00E-03	-2.198	9	.056
Pair 9	ALT2 - ALT6	-7.07E-02	4.18E-03	1.32E-03	-7.50E-02	-6.64E-02	-53.505	9	.000
Pair 10	ALT3 - ALT4	6.06E-02	1.03E-02	3.26E-03	5.00E-02	7.12E-02	18.576	9	.000
Pair 11	ALT3 - ALT5	5.84E-02	7.37E-03	2.33E-03	5.09E-02	6.60E-02	25.069	9	.000
Pair 12	ALT3 - ALT6	-8.05E-03	1.03E-02	3.25E-03	-1.86E-02	2.53E-03	-2.473	9	.035
Pair 13	ALT4 - ALT5	-2.12E-03	6.77E-03	2.14E-03	-9.08E-03	4.84E-03	-.989	9	.348
Pair 14	ALT4 - ALT6	-6.86E-02	4.42E-03	1.39E-03	-7.32E-02	-6.41E-02	-49.092	9	.000
Pair 15	ALT5 - ALT6	-6.65E-02	4.82E-03	1.52E-03	-7.15E-02	-6.15E-02	-43.576	9	.000

Table E.5. Paired samples test of alternatives for frequency of controlling

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	99% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ALT1 - ALT2	-1106.91	29.38894	9.29359	-1137.11	-1076.71	-119.105	9	.000
Pair 2	ALT1 - ALT3	168.758	17.52711	5.54256	150.7459	186.7707	30.448	9	.000
Pair 3	ALT1 - ALT4	.872619	28.50020	9.01255	-28.41671	30.16194	.097	9	.925
Pair 4	ALT1 - ALT5	-1099.78	27.9340	8.83352	-1128.495	-1071.08	-124.502	9	.000
Pair 5	ALT1 - ALT6	180.9273	27.3888	8.66111	152.7801	209.0745	20.890	9	.000
Pair 6	ALT2 - ALT3	1275.674	29.5194	9.33485	1245.338	1306.011	136.657	9	.000
Pair 7	ALT2 - ALT4	1107.78	17.2093	5.44207	1090.103	1125.47	203.560	9	.000
Pair 8	ALT2 - ALT5	7.128571	23.4478	7.41486	-16.9685	31.2256	.961	9	.361
Pair 9	ALT2 - ALT6	1287.844	18.1738	5.74707	1269.166	1306.521	224.087	9	.000
Pair 10	ALT3 - ALT4	-167.885	28.0247	8.86221	-196.686	-139.084	-18.944	9	.000
Pair 11	ALT3 - ALT5	-1268.54	27.7290	8.76869	-1297.04	-1240.049	-144.668	9	.000
Pair 12	ALT3 - ALT6	12.1690	25.5499	8.07961	-14.08836	38.42646	1.506	9	.166
Pair 13	ALT4 - ALT5	-1100.66	25.8839	8.18523	-1127.26	-1074.060	-134.469	9	.000
Pair 14	ALT4 - ALT6	180.0547	11.4928	3.63436	168.243	191.865	49.542	9	.000
Pair 15	ALT5 - ALT6	1280.715	20.63393	6.52502	1259.510	1301.920	196.278	9	.000

Table E.6a. Pairwise comparison matrix of alternatives for ratio of illegal infiltrations caught criterion

alternatives	1	2	3	4	5	6
1	1.0000	0.2049	0.4651	0.8130	0.2000	0.3890
2	4.8804	1.0000	3.7223	4.6413	0.8938	3.3050
3	2.1501	0.2687	1.0000	1.9189	0.2603	0.7055
4	1.2300	0.2155	0.5211	1.0000	0.2096	0.4273
5	5.0000	1.1188	3.8417	4.7710	1.0000	3.0370
6	2.5707	0.3026	1.4174	2.3403	0.3293	1.0000

Table E.6b. Pairwise comparison matrix of alternatives for degree of controllability criterion

alternatives	1	2	3	4	5	6
1	1.0000	0.8922	0.2192	0.8091	0.7401	0.2000
2	1.1208	1.0000	0.2252	0.8966	0.8127	0.2049
3	4.5620	4.4405	1.0000	4.3251	4.2098	0.6949
4	1.2359	1.1153	0.2312	1.0000	0.8966	0.2099
5	1.3512	1.2305	0.2375	1.1153	1.0000	0.2151
6	5.0000	4.8804	1.4391	4.7642	4.6490	1.0000

Table E.6c. Pairwise comparison matrix of alternatives for frequency of controlling criterion

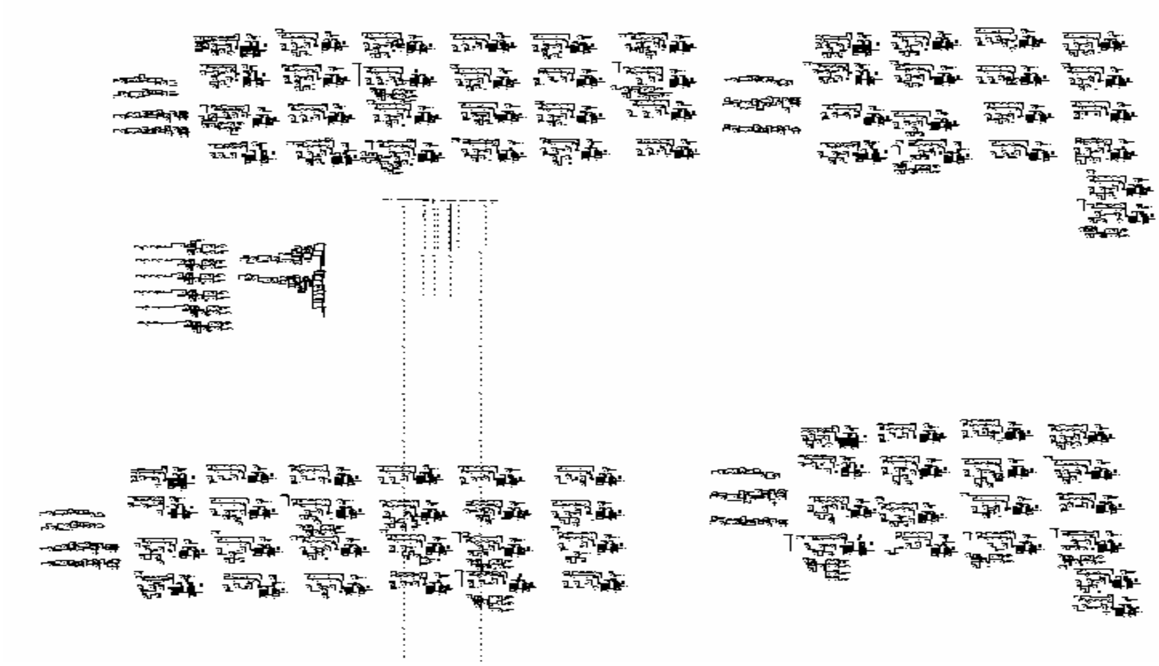
alternatives	1	2	3	4	5	6
1	1.0000	0.2253	1.5248	1.0000	0.2264	1.5621
2	4.4385	1.0000	4.9627	4.4409	1.0000	5.0000
3	0.6558	0.2015	1.0000	0.6571	0.2023	1.0000
4	1.0000	0.2252	1.5218	1.0000	0.2262	1.5590
5	4.4170	1.0000	4.9432	4.4209	1.0000	4.9782
6	0.6402	0.2000	1.0000	0.6414	0.2009	1.0000

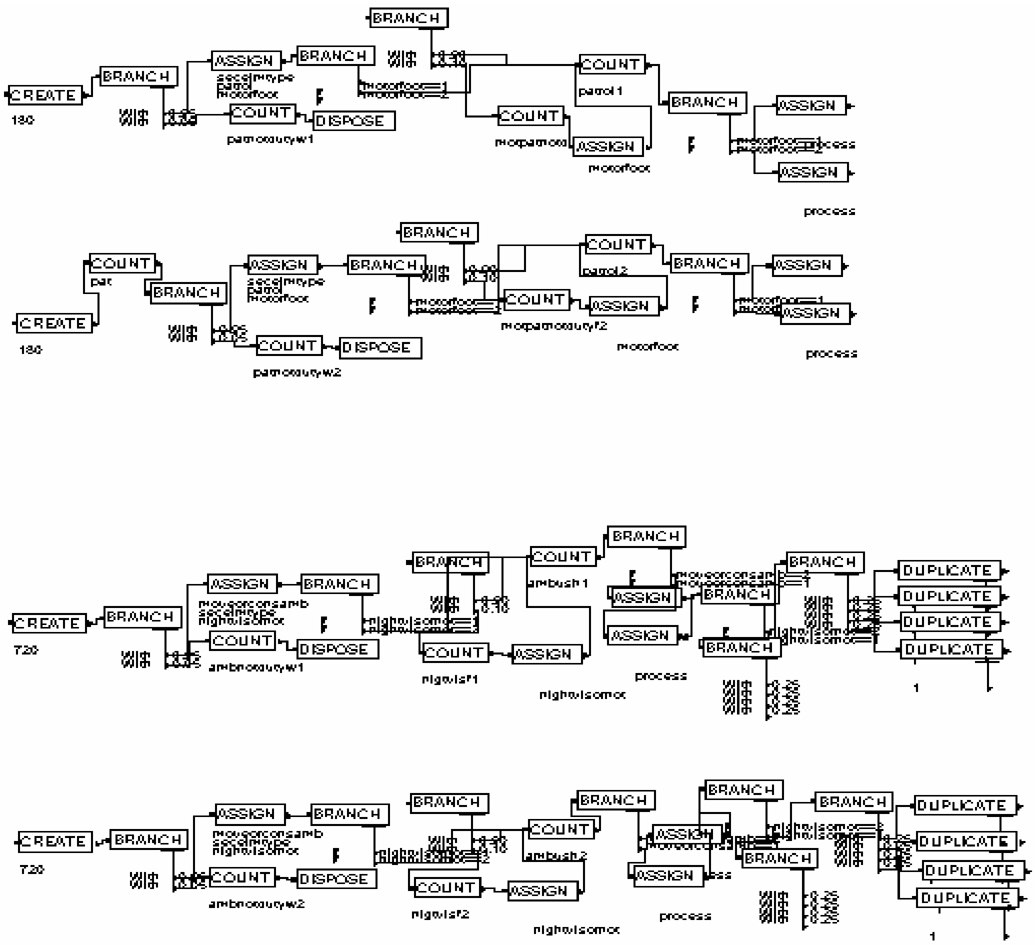
Table E.6d. Pairwise comparison matrix of alternatives for cost criterion

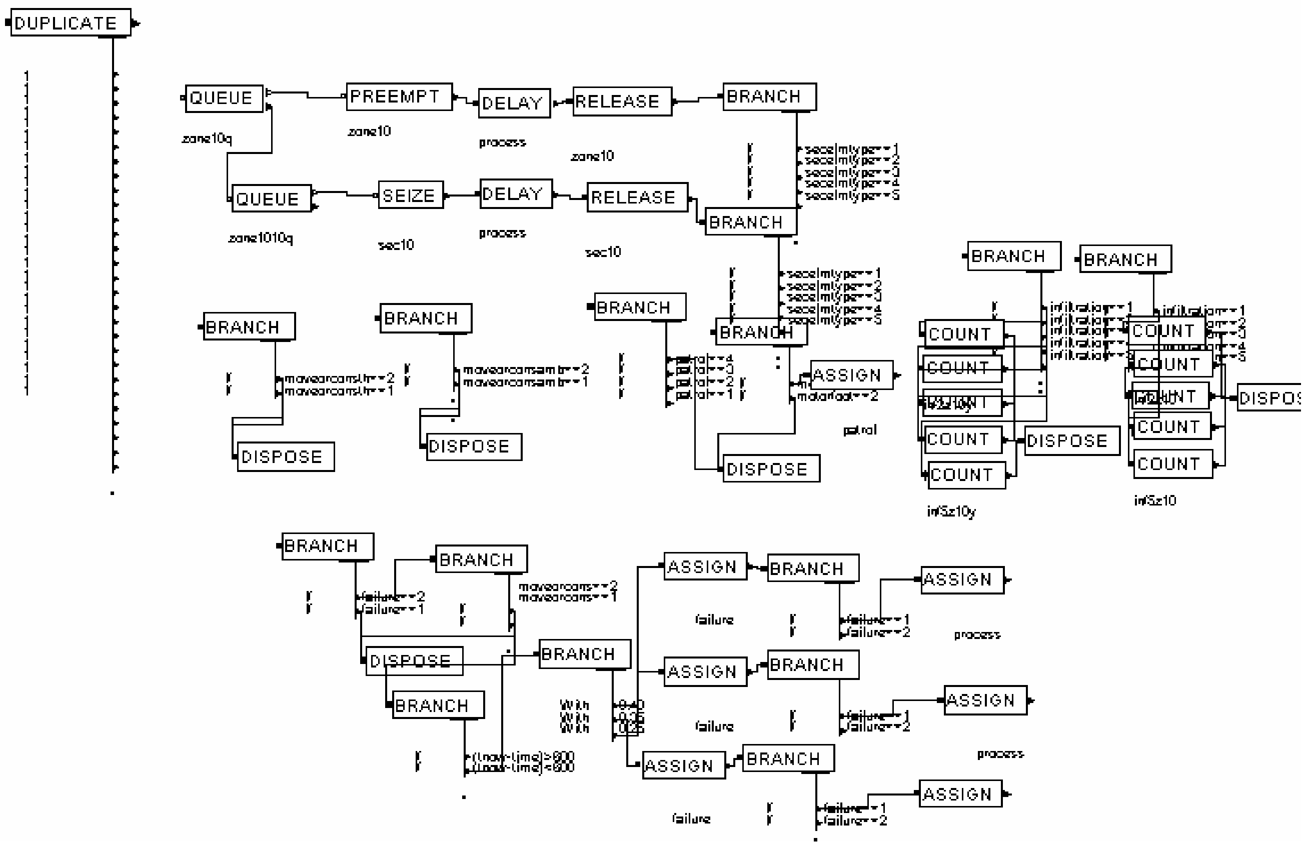
alternatives	1	2	3	4	5	6
1	1.0000	2.6600	5.0000	1.0000	2.6600	5.0000
2	0.3759	1.0000	3.3300	0.3750	1.0000	3.3300
3	0.2000	0.3003	1.0000	0.2000	0.3000	1.0000
4	1.0000	2.6667	5.0000	1.0000	2.6600	5.0000
5	0.3759	1.0000	3.3333	0.3759	1.0000	3.3300
6	0.2000	0.3003	1.0000	0.2000	0.3003	1.0000

APPENDIX F

Computer Code of Border Security System



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QUEUE
PREEMPT
DELAY
RELEASE
BRANCH
zone10q
zone10
process
zone10
QUEUE
SEIZE
DELAY
RELEASE
BRANCH
zone1010q
sec10
process
sec10
BRANCH
BRANCH
BRANCH
BRANCH
BRANCH
BRANCH
ASSIGN
DISPOSE
DISPOSE
DISPOSE
COUNT
COUNT
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COUNT
COUNT
DISPOSE
patrol
infSz10y
infSz10
BRANCH
BRANCH
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DISPOSE
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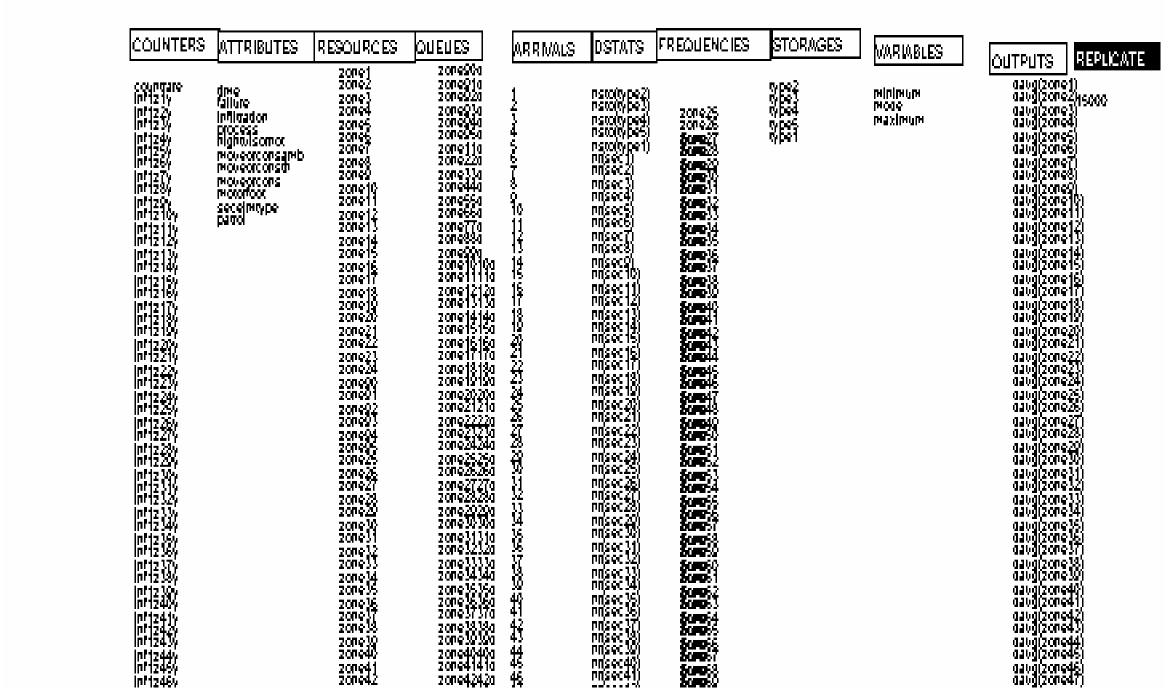
failure
failure
process
process


COUNTERS
ATTRIBUTES
RESOURCES
QUEUES
ARRIVALS
DSTATS
FREQUENCIES
STORAGES
VARIABLES
OUTPUTS
REPLICATE

APPENDIX G

Input Data

We define the input data we use in our model.

Arrival process of illegal infiltrations is best defined by Poisson process. Because; (1) illegal infiltrations arrive one at a time for each zone, (2) *N(t+s)-N(t)* (the number of arrivals in the time interval *(t,t+s)* is independent of *{N(u), 0<=u<=t}*, (3) the distribution of *N(t+s)-N(t)* is independent of *t* for all *t,s>=0.* We know that Poisson process is an arrival process for which the interarrival times between arrivals are identically independent distributed exponential random variables. We decide the parameters of the exponential distribution as seen in Table G.1 according to number of illegal infiltrations that is probable in one year of time period by asking military experts. We also determine the parameters of discrete distribution for type of illegal infiltrations and parameters of triangular distribution for infiltration time of each type of infiltration by consulting specialists as seen in Table G.2-G.3.

Table G.1. Arrivals of illegal infiltrations

illegal infiltrations for critical zones	exponential(2500)
Illegal infiltrations for uncritical zones	exponential(7000)

Table G.2. Type of illegal infiltrations

refugees	terrorists	smugglers	enemy special forces	enemy troops
35%	30%	25%	5%	5%

Table G.3. Infiltration time of illegal infiltrations

	refugees	terrorists	smugglers	enemy special forces	enemy troops
infiltration time	tria(60,75,90)	tria(20,25,30)	tria(40,50,60)	tria(10,15,20)	tria(30,40,50)

We decide parameters of triangular distribution for duty time of patrols (according to motorized or on-foot) and duty time of other security elements (according to stationary or moving) as seen in Table G.4-G.5, by using information given in border services instructions (KKY 118-1). Duty time when failure occurs is determined according to duty time of elements as seen in Table G.6.

Table G.4. Duty time of patrols

		motorized	on-foot
1st platoon	1st patrol	triangular(4,5,6)	triangular(8,10,12)
	2nd patrol	triangular(3,4,5)	triangular(6.5,7.5,8.5)
2nd platoon	patrol	triangular(4,5,6)	triangular(8,10,12)
3rd platoon	patrol	triangular(4,5,6)	triangular(8,10,12)
4th platoon	1st patrol	triangular(2,3,4)	triangular(4.5,6,7.5)
	2nd patrol	triangular(4,5,6)	triangular(8,9,10)

Table G.5. Duty time of ambushes, thermal camera and askarad

	stationary duty	mobile duty
ambushes	triangular(600,630,660)	triangular(120,150,180)
thermal camera	triangular(600,630,660)	triangular(160,200,240)
askarad	triangular(600,630,660)	triangular(160,200,240)

Table G.6. Duty time when failure happened

	stationary duty	mobile duty
thermal camera	uniform(0,600)	uniform(0,160)
askarad	uniform(0,600)	uniform(0,200)

We decide the parameters of discrete distribution for weather conditions and failures before duty as seen in Table G.7-G.8, by using established statistics gained by experiences and asking military experts.

Table G.7 Weather conditions

Bad weather conditions	appropriate weather conditions for duty
0.05	0.95

Table G.8 Failure conditions

	Failure before duty	No failure before duty
Askarad Thermal camera Night-vision tool Vehicle for patrol	10%	90%

The parameters of discrete distribution presented in Tables G.9-G.12 are controllable parameters of the model. By using statistics gained by experiences and consulting to specialists, we decide the parameters of these random variables (stationary or mobile characteristics of duty, type of patrols, degree of use of night-vision tools by ambushes, degree of use of technologic devices).

Table G.9. Stationary or mobile characteristics of duty

	stationary	mobile
ambushes	0.70	0.30
thermal camera	0.70	0.30
askarad	0.70	0.30

Table G.10. Type of patrols

	motorized	on-foot
1st platoon	0.15	0.85
2nd platoon	0.25	0.75
3rd platoon	0.25	0.75
4th platoon	0.20	0.80

Table G.11. Degree of use of night-vision tools by ambushes

	with night-vision device	without night-vision device
ambushes	0.25	0.75

Table G.12. Degree of use of technologic devices

	will be used	will not be used
askarad thermal	60%	40%

The parameters of discrete distribution presented in Table G.13-G.18 are determined by using information about operational behavior of border security system and consulting to experts. Because, events in the system, such as selection of duty places for each security element and selection of another duty place after end of duty at any place if security elements have mobile characteristic, represent the operational behavior of the system. In Tables G.13-G.18, zone codes and parameters of discrete distribution are presented for each security elements according to their characteristics.

Table G.13a. Determination of first duty place of ambushes of 1st platoon

1st platoon	probabilities		**25%**	**25%**	**25%**	**25%**
	1st ambush	with night-vision tool	z1z2	z5z6	z8z9	z11z12
		without tool	z2	z6	z9	z12
	2nd ambush	with night-vision tool	z14z15	z16z17	z19z20	z20z21
		without tool	z15	z17	z20	z21

Table G.13b. Determination of first duty place of ambushes of 2nd platoon

2nd platoon	1st ambush	probabilities	**33%**	**33%**	**33%**	
		with night-vision tool	z26z25	z30z29	z32z31	
		probabilities	**25%**	**25%**	**25%**	**25%**
		without tool	z25	z29	z31	z28
	2nd ambush	probabilities	**50%**		**50%**	
		with night-vision tool	z38z37		z41z40	
		probabilities	**25%**	**25%**	**25%**	**25%**
		without tool	z35	z37	z40	z42

Table G.13c. Determination of first duty place of ambushes of 3rd platoon

3rd platoon	1st ambush	probabilities	**33%**	**33%**	**33%**	
		with night-vision tool	z46z45	z49z48	z53z52	
		probabilities	**25%**	**25%**	**25%**	**25%**
		without tool	z43	z45	z48	Z52
	2nd ambush	probabilities	**50%**		**50%**	
		with night-vision tool	z56z55		z59z58	
		probabilities	**50%**		**50%**	
		without tool	z55		z58	

Table G.13d. Determination of first duty place of ambushes of 4th platoon

4th platoon	probabilities		**33%**	**33%**	**33%**
	1st ambush	with night-vision tool	z64z63	z67z66	z71z70
		without tool	z63	z66	z70
	2nd ambush	with night-vision tool	z75z74	z79z78	z83z82
		without tool	z74	z78	z82

Table G.14. Determination of first duty place of thermal camera

probability	11%
Zone code	z3,z12,z22,z32,z42,z54,z58,z70,z79

Table G.15. Determination of first duty place of askarad

probability	11%
Zone code	Z10,z46,z80,z90,z91,z92,z93,z94,z95

Table G.16. Determination of next duty place of thermal camera

	z3	z12	z22	z32	z42	z54	z58	z70	z79
z3	---	0.75	0.25	---	---	---	---	---	---
z12	0.50	---	0.50	---	---	---	---	---	---
z22	0.34	0.33	---	0.33	---	---	---	---	---
z32	---	---	0.50	---	0.50	---	---	---	---
z42	---	---	---	0.50	---	0.50	---	---	---
z54	---	---	---	---	0.50	---	0.50	---	---
z58	---	---	---	---	---	0.50	---	0.50	---
z70	---	---	---	---	---	---	0.50	---	0.50
z79	---	---	---	---	---	---	0.30	0.70	---

Table G.17. Determination of next duty place of askarad

	z90	z91	z92	z10	z46	z80	z93	z94	z95
z90	---	0.75	0.25	---	---	---	---	---	---
z91	0.50	---	0.50	---	---	---	---	---	---
z92	---	0.50	---	0.50	---	---	---	---	---
z10	---	---	0.35	---	0.40	0.25	---	---	---
z46	---	---	0.20	0.30	---	0.30	0.20	---	---
z80	---	---	---	0.25	0.40	---	0.35	---	---
z93	---	---	---	---	---	0.50	---	0.50	---
z94	---	---	---	---	---	---	0.50	---	0.50
z95	---	---	---	---	---	---	0.25	0.75	---

Table G.18a. Determination of next duty place of 1st platoon 1st ambush with night-vision

	z1z2	z5z6	z8z9	z11z12
z1z2	---	0.75	0.25	---
z5z6	0.50	---	0.50	---
z8z9	---	0.50	---	0.50
z11z12	---	0.25	0.75	---

Table G.18b. Determination of next duty place of 1st platoon 1st ambush without nightvision

	z2	z6	z9	z11
z2	---	0.75	0.25	---
z6	0.50	---	0.50	---
z9	---	0.50	---	0.50
z11	---	0.25	0.75	---

Table G.18c. Determination of next duty place of 1st platoon 2nd ambush with night-vision

	z14z15	z16z17	z19z20	z20z21
z14z15	---	0.75	0.25	---
z16z17	0.50	---	0.50	---
z19z20	---	0.50	---	0.50
z20z21	---	0.25	0.75	---

Table G.18d. Determination of next duty place of 1st platoon 2nd ambush without night-vision

	z15	z17	z20	z21
z15	---	0.75	0.25	---
z17	0.50	---	0.50	---
z20	---	0.50	---	0.50
z21	---	0.25	0.75	---

Table G.18e. Determination of next duty place of 2nd platoon 1st ambush with night-vision

	z26z25	z30z29	z32z31
z26z25	---	0.65	0.35
z30z29	0.50	---	0.50
z32z31	0.35	0.65	---

Table G.18f. Determination of next duty place of 2nd platoon 1st ambush without night-vision

	z26z25	z30z29	z32z31
z26z25	---	0.65	0.35
z30z29	0.50	---	0.50
z32z31	0.35	0.65	---

Table G.18g. Determination of next duty place of 2nd platoon 2nd ambush with night-vision

	z38z37	z41z40
z38z37	---	1
z41z40	1	---

Table G.18h. Determination of next duty place of 2nd platoon 2nd ambush without night-vision

	z35	z37	z40	z42
z35	---	0.75	0.25	---
z37	0.50	---	0.50	---
z40	---	0.50	---	0.50
z42	---	0.25	0.75	---

Table G.18i. Determination of next duty place of 3rd platoon 1st ambush with night-vision

	z46z45	z49z48	z53z52
z46z45	---	0.65	0.35
z49z48	0.50	---	0.50
z53z52	0.35	0.65	---

Table G.18j. Determination of next duty place of 3rd platoon 1st ambush without night-vision

	z43	z45	z48	z52
z43	---	0.75	0.25	---
z45	0.50	---	0.50	---
z48	---	0.50	---	0.50
z52	---	0.25	0.75	---

Table G.18k. Determination of next duty place of 3rd platoon 2nd ambush with night-vision

	z56z55	z59z58
z56z55	---	1
z59z58	1	---

Table G.18l. Determination of next duty place of 3rd platoon 2nd ambush without night-vision

	z55	z58
z55	---	1
z58	1	---

Table G.18m. Determination of next duty place of 4th platoon 1st ambush with night-vision

	z64z63	z67z66	z71z70
z64z63	---	0.65	0.35
z67z66	0.50	---	0.50
z71z70	0.35	0.65	---

Table G.18n. Determination of next duty place of 4th platoon 1st ambush without night-vision

	z64z63	z67z66	z71z70
z64z63	---	0.65	0.35
z67z66	0.50	---	0.50
z71z70	0.35	0.65	---

Table G.18o. Determination of next duty place of 4th platoon 2nd ambush with night-vision

	z75z74	z79z78	z83z88
z75z74	---	0.65	0.35
z79z78	0.50	---	0.50
z83z82	0.35	0.65	---

Table G.18p. Determination of next duty place of 4th platoon 2nd ambush without night-vision

	z74	z78	z82
z74	---	0.65	0.35
z78	0.50	---	0.50
z82	0.35	0.65	---

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